Energy and Economic Implications of Carbon Neutrality in China – A Dynamic General Equilibrium Analysis

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Energy and Economic Implications of Carbon Neutrality in China – a Dynamic General Equilibrium Analysis

Shenghao Feng[1], Xiujian Peng[2], Philip Adams[3]

Abstract

This study investigates the energy and economic implications of China's carbon neutrality path over the period of 2020 to 2060. We use a recursive dynamic CGE model, CHIANGEM-E, to conduct the analysis. Notable advancements from the original CHINAGEM model include: 1) detailed energy sector disaggregation, 2) a new electricity generation nesting structure, and 3) carbon capture and storage (CCS) mechanisms. Our simulation shows that to achieve carbon neutrality in 2060, China needs change its energy consumption structure significantly. Coal and gas consumption will decline dramatically while the demand for renewable energy, especially demand for solar and wind energy will increase considerably. However, the negative effects of the dramatic carbon emission reduction on China's macro economy is limited. In particular, by 2060 real GDP will be 1.36 percent lower in carbon neutrality scenario (CNS) than in the base case scenario. The carbon price level will be 1614 CNY per tonne of carbon dioxide in 2060 in CNS.

The substantial changes in China's energy structure imply significant changes to its fossil fuel imports. China's import demand for coal, crude oil and gas will all fall sharply. By 2060, China's imports of coal and gas will be more than 60% lower and its oil imports will be around 50% lower than their respective base-case levels.

Key words: Carbon neutrality, economic implication, energy consumption, China, CGE
JEL: C68, E17, Q43, Q47, Q48, Q54.

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1. Introduction

China has a range of long-, medium-, and short-term energy and emissions reduction targets. On September 22nd, 2020, China's president Xi Jinping announced that China aims to peak carbon dioxide emissions before 2030 and to reach carbon neutrality before 2060. On December 12th, 2020, president Xi announced details of China's long-term low greenhouse gas development strategies. The strategies set targets for 2030, including: 1) reducing emissions intensity of GDP by more than 65% compared to the 2005 level; 2) increasing non-fossil fuel share in total energy consumption to around 25%, and 3) increasing the combined installed capacity of wind and solar power to more than 1.2 terawatt. China's 14th Five Year Plan (14th FYP) sets targets for 2025. It aims to reduce emissions intensity of GDP and energy intensity of GDP by 18% and 13.5%, respectively, between 2020 and 2025. Climate mitigation is also elevated as a major economic task for the first time in 2021. Specific jobs include: 1) formulating an action plan for peaking carbon emissions before 2030, 2) peaking coal consumption as soon as possible, 3) controlling total energy consumption as well as energy intensity of GDP, among others. Reaching carbon neutrality before 2060 is China's longest term climate mitigation commitment to date. Other targets shall be designed in consistent with this overarching target.

We use a computable general equilibrium (CGE) model to investigate the energy and economic implications of reaching carbon neutrality in China. The energy system is deeply embedded in the economic system. It is unrealistic to formulate energy development plans against various energy and emissions targets without understandings of the interactions between the energy and the economic system. For example, a change of an energy price might change demand for capital in each sector, which may change capital price in the entire economy, and, in turn, affect all sectors of the economy. Likewise, it is inadequate to forecast economic development paths without incorporating changes in the energy system. CGE models are suitable to tackle such interactions (Fujimori et al., 2014, Otto et al., 2007, Bataille et al., 2006). They could project development paths for energy and economic systems in a consistent manner. This is because CGE models can channel the impacts of mitigation efforts through input-output linkages, and various price-, technology-, and/or preference-induced, behavioral changes throughout the entire economic system. Indeed, CGE models have been widely used in energy and climate policy analysis (Beckman et al., 2011, Böhringer and Löschel, 2006, Hermeling et al., 2013, Allan et al., 2014, Babatunde et al., 2017).

Another reason for using CGE modelling is our focus on the macroeconomic and the sector level. Ours thus can be seen as the medium-level analysis. At the higher-level, there are models that integrate economic systems with environmental systems. These are often referred as integrated assessment models (IAMs). Examples include the DICE and RICE models (Nordhaus and Yang, 1996, Nordhaus, 1992). Their strengths lie within their abilities to study the interactions between the energy, economic and environmental or ecological systems at long time scales. Although their economic modules also rely on the CGE modelling framework, they lack detailed production, consumptions systems or rich sector-level details of large-scale CGE models (such as the one used in our study). At the lower-level, there are various sector-specific models, such as electricity market models, transportation system models or forestry system models, and *etc*. (Jewell, 2011, Kurz et al., 2009, Wang et al., 2008). Such models have richer technical details than traditional CGE models but often need to rely on exogenous assumptions for demand forecasts. CGE modelling is thus the ideal tool for analyzing carbon neutrality implications at the macroeconomic and sector levels.

We give emphasis to the modelling of carbon capture and storage (CCS) applications in China. CCS is an indispensable technological choice in the global quest for carbon neutrality (Guo and Huang, 2020, Paltsev et al., 2021). This is especially true for China. China has rich coal reserve and can produce coal at moderate costs compared to oil and gas (Fan et al., 2018, Jia and Lin, 2021). Coal-fired power generation can serve as back-up units to enhance the stability and flexibility of China's massive power system (Zhu et al., 2017, Yin et al., 2017). The captured carbon dioxide can also be used to enhance the extraction of oil (Tapia et al., 2016, Jiang et al., 2019) or to facilitate the production of hydrogen fuel[4] (Quarton and Samsatli, 2020, Hancock and Ralph, 2021). There however has been few studies on carbon neutrality that has modelled CCS explicitly. Our study incorporates a mechanism to model the application of CCS endogenously. By 'endogenously' we mean that both the amount of total CO2 emissions and the emissions that are captured by CCS facilities are generated endogenously. To do so we exogenously assume the penetration rate of CCS facilities.

The rest of the paper is organized as the following: Section 2 identifies six gaps in the literature. Section 3 shows the modelling advancements made from our starting point, the CHINAGEM model. Section 4 explains the assumptions given in the two main scenarios, namely the base-case scenario (BCS) and the carbon neutrality scenario (CNS). Section 5 discusses the results of the two main scenarios. Section 6 compares results of the main carbon neutrality scenario with 14 alternative carbon neutrality scenarios. Section 7 is conclusion and policy implications.

2. Literature review

We identify six gaps in the literature and make amends in the current study where possible. First, there is a lack of analysis on the economic implications of reaching carbon neutrality in China at the macroeconomic and sector levels. The literature has been more focused on the energy development path itself. A few important reports have presented views on the future of China's energy development paths. Project Synthesis Report Writing Group (2020), China National Petroleum Corporation Economic and Technology Research Institute (2020), Energy Foundation China (2020), and Goldman Sachs (2020) have all expressed their views regarding China's carbon neutrality paths in the energy space. Macroeconomic variables that have received enough attention in these studies include real GDP, employment, capital stock, consumption, investment, trade, as well as levels of carbon prices. Changes in these macroeconomic variables could have profound implications to impacts on individual sectors. Regarding sectors, the existing literature generally only consider the impacts on energy intensive sectors, namely the power sector, the transportation sector, the heavy industry sector, and the building sector. They rarely consider the impacts on non-energy intensive sectors, especially those with many employed persons (*e.g.*, Wholesale and Retail, Public Administration, *etc.*.). Changes in these sectors' output could affect economy-wide employment levels. The current study pays more attention to the macroeconomic and sector level implications than the existing studies.

Second, there is a lack of analyses with the specific target of carbon neutrality in 2060. A few existing studies set the final year of their analyses to 2050. This would not necessarily provide a full picture as to how would China complete its last, and arguably the more difficult, part of the carbon neutrality

[4] These are often referred as CCUS (carbon capture utilization and storage) technologies

challenge. Some existing studies have not modelled a carbon neutrality path explicitly. Instead, their scenarios are framed as 1.5℃ and 2℃ scenarios. Indeed, some new but unpublished works have amended these limitations (e.g., Liu (2020), Zhang (2020)). Our study belongs to these new studies.

Third, there is a lack of underlying assumption provided by many similar studies in the field. CGE modelers often face difficult decisions when making assumptions on energy efficiency or energy preference changes. Such difficulties stem from the fact that predictions on energy efficiency or preference changes are often hard to come by and are subject to many uncertainties. Yet, variations in such assumptions may alter simulation results in non-negligible ways. It is thus necessary to state these assumptions clearly so that readers can comprehend and compare simulation results among different studies. This study provides a full account of the assumptions made in our scenarios. Moreover, we also test variations in these changes in our alternative scenarios.

Fourth, the existing literature still has some way to go to develop an appropriate fuel-factor nesting structure with related substitution parameters for CGE models of China. It has long been recognized that inter-fuel and inter-factor substitution parameters are important to CGE modelling results (Bhattacharyya, 1996). It is only until recently that the literature began to investigate the implication of different nesting structures though. Zha and Zhou (2014) was the first attempt to find an appropriate top-level (the labor-capital-energy nesting level) fuel-factor nesting structure for China. Their work, however, does not employ a CGE model to test the implications of different nesting structures. Feng and Zhang (2018) was the first to do so. In addition, they propose a strategy to compare between different nesting structures. Yet, their work also remains at the top nesting level. Cui et al. (2020) extends these works by comparing two different nesting structures within the electricity generation nest. The current work extends the existing works by adding more lower-level nest in the electricity production nest. The purpose is to allow more targeted substitution between power generated from different fuels. We will explain our nesting structure choices, as well as the corresponding substitution parameter choices in subsection 3.3.

Fifth, there lacks a full account of CCS, BECCS (Bioenergy CCS) and DACCS (Direct Air CCS) applications in CGE modelling in the context of China reaching carbon neutrality. Vennemo et al. (2014) is the only attempt that has explicitly treated CCS in the CGE modelling in the context of China. They disaggregated coal-fired and gas-fired power generation sectors between ones with CCS and ones without CCS. They then put all different power generation types, including hydropower and nuclear, within a same power generation nest, and applying a constant elasticity of substitution parameter being 20. They estimated that a carbon price of 500 CNY per tonne of carbon dioxide (tCO2) in 2050 is required to compensate the installation of 98% of the coal-fired units with CCS, and that this would reduce GDP by 4%. Their work however was done before the carbon neutrality target was announced and thus did not become part of the analysis in a carbon neutrality scenario. Moreover, they only considered coal-fired power CCS, but did not consider CCS application in other stationary point, such as steel or cement production. Likewise, some recent studies have also incorporated BECCS technologies (Weng et al., 2021, Huang et al., 2020), but did not combine all three of CCS, BECCS and DACCS to form a carbon neutrality scenario either. This study provides a carbon neutrality scenario considering the contribution from all three negative-emissions technologies.

Sixth, there lacks comparison scenarios should some of the assumptions or parameters vary. Modelling a carbon neutrality path involves making many assumptions. Nearly all assumptions can vary. It is thus important to recognize the implications of changes in these assumptions to changes in overall modelling results. Most of the exiting pathway analyses only provide single scenarios to 1.5℃ or 2℃. Few have shown the many possible scenarios upon changes in the underlying assumptions. The current study fills this gap by testing 15 alternative scenarios.

This study contributes to the literature in six aspects. These six aspects are related to the six gaps. First, this is a study that focuses on the macroeconomic and sector level results, in terms of not only economic and but also energy. Second, our study is the first research focuses on a carbon neutrality scenario in China and our simulations end in year 2060. Third, we detail our crucial assumptions in terms of energy efficiency and preference changes. Fourth we incorporate a new, multi-level fuel-factor nesting structure with multiple layers below the electricity generation nest. Fifth, we include CCS, BECCS and DACCS in our carbon neutrality scenarios. Regarding, CCS, we model CCS application for three different fuel types, namely coal, oil, and gas, in three broad sectors, namely chemicals, steel, cement and thermal power. Six, we compare 14 alternative scenarios with our main carbon neutrality scenario to help to understand the implications of changes in the assumption amid uncertainties.

3. Modelling advancements

This study uses the CHINAGEM-E model to conduct the analysis. CHINAGEM-E is a recursive dynamic computable general equilibrium (CGE) model of the Chinese economy with additional treatment for energy and carbon dioxide emissions. The core model, including the input-output structure, the production theory, the final demand mechanisms, the labor and capital dynamisms, and various miscellaneous equations, is based on the generic CHINAGEM model (Mai et al., 2010). The core database is the latest 2017 Input-output Table of China. We made five energy-related developments based on the core model and database:

1) Disaggregation of energy sectors
2) Addition of energy and emissions accounts
3) Addition of a new fuel-factor nesting structure with calibrations of parameters
4) Carbon pricing mechanism and revenues recycling mechanisms
5) Carbon capture and storage mechanisms

Subsections 3.1-3.5 explain these model developments.

3.1 Disaggregation of energy sectors

We disaggregated the CrudeOilGas[5] and Electricity sectors[6] in the original database. Reaching carbon neutrality requires profound structural changes within the energy system. The composition between crude oil and gas, and more importantly, that between fossil fuel-based power and non-fossil fuel-base power, shall change. These two sectors are clearly inadequate to conduct such

[5] This is an abbreviation for a sector (Crude oil and gas) in the original input-output table..

[6] by 'sectors', we mean both commodities and industries, as the original IO table is symmetric.

analysis.

The original CHINAGEM database has 149 sectors. We disaggregated it into 157 commodities and 159 industries[7],[8]. This allows the model to have more detailed energy types and therefore to do more detailed energy- and emissions-related analyses. Two original sectors are disaggregated, namely 1) Crude Oil and Gas, and 2) Electricity.

First, we split the old crude oil and gas (CrudeOilGas) sector into two separate ones, namely Crude Oil, and Gas. We use value shares to split both commodities and industries. The physical quantity data are obtained from China Energy Statistical Yearbook and the price data are deduced from the Chinese Custom (for import value) and China Energy Statistical Yearbook (for import quantity). Thus we use import prices as proxies for domestic prices of crude oil and gas. When splitting commodities, we also make two additional assumptions. On the one hand, we assume CrudeOil only sells to the Petroleum Refinery industry and no Gas is sold to Petroleum Refinery. On the other hand, we assume that only Gas is sold to users other than Petroleum Refinery. We then further disaggregate the gas industry into conventional and non-conventional gas industries. These two industries produce the same commodity-gas.

Second, following Adams and Parmenter (2013) we first separate electricity generation and distribution. We then split electricity generation into eight commodities and nine industries. The eight commodities are technologies, namely coal-fired power, gas-fired power, nuclear power, hydropower, solar power, wind power, bioelectricity, and power generation & distribution. Each electricity commodity is produced by its corresponding industry, except wind power. The wind power industry is further disaggregated into onshore wind power and offshore wind power. They both produce the same commodity - wind power. We also use value shares to split both commodities and industries. The quantity data are obtained from China Electric Power Yearbook. The price data are provided by China Energy. When splitting commodities, we assume electricity generation outputs of all types are sold only to the power transmission and distribution industry.

3.2 Energy and emissions accounts

The basic input-output database is a value database (i.e., price times quantities). To have standard energy or emissions quantities, we need to set up separate energy and emissions accounts and link them with real quantity variables in the CGE model. We added four separate energy and emissions accounts, they are:

1) Primary energy consumption in 2017: we distinguish eight types of primary energy, namely coal, oil, gas, hydropower, nuclear power, wind power, solar power, and bioelectricity. The data is taken from China Energy Statistical Yearbook 2018, with the unit of 10,000 tons of standard coal equivalent (sce), using coal equivalent calculation (cec).We allocate the quantities of the eight

[7] There is one more industry than commodity as commodity "wind power" is produced by two industries, namely "onshore wind power" and "offshore wind power"

[8] For comprehensive lists of industries and commodities of the current model database, please refer to Appendix 1 and Appendix 2, respectively.

energy to the 160 fuel users (159 industry users and 1 residential user) according to the input-output table sales structure of their corresponding energy commodities.

2) Final energy consumption in 2017: we distinguish fourteen types of final energy, namely coal, oil, gas, petroleum, coke, coal-fired power, gas-fired power, hydropower, nuclear power, onshore wind power, offshore wind power, solar power and bioelectricity, and gas supply. They are allocated in the same way as primary energy, using the same data source, the same energy unit, but are calculated by the coal calorific calculation (ccc) method.
3) Electricity generation by fuel types in 2017: we distinguish seven power generation technologies, namely coal-fired power, gas-fired power, nuclear power, hydropower, solar power, wind power and bioelectricity. The data are taken from China Electric Power Yearbook. They are also allocated in the same way as primary energy. The energy unit is 100mKWh.
4) CO2 emissions by fuel in 2020: we distinguish four types of gas emitting fuels, namely coal, gas, petroleum, and gas supply. We set the total level of carbon dioxide emissions in 2020 to be 9.88 billion tons. We allocate CO2 emissions from each of these four types of fuel to each of the 160 fuel users based on their sales shares in the I/O table.

3.3 Multi-level fuel-factor production nests with a new power generation nesting structure and parameters

Conventional CGE models do not allow input-substitutions among production factors and different types of energy. We create a new fuel-factor nesting structure to allow substitutions between production factors and different types of energy. More specifically, it has a new power generation nesting structure. The full nesting structure is shown in **Error! Reference source not found.**, and the values of the substitution parameters are shown in **Table 1**.

On the top level, labor, land, and a capital-energy composite form a constant elasticity of substitution (CES) nest. Feng and Zhang (2018) found that a capital-energy CES composite is preferred to a capital-labor CES composite in the context of China. Using a consistent econometric framework and Chinese data, Feng and Zhang (2018) found that the CES parameter between labor and a capital-energy composite for China is 0.78. The capital-energy composite is a CES nest of capital and an energy composite. The corresponding CES parameter is 0.72 (Feng and Zhang (2018). The energy composite is a CES nest of an electricity nest and a non-electricity nest and the corresponding CES parameter for China is 1.85 (Zhang and Feng, 2021).

The non-electricity nest is first a CES composite of a coal-composite and a non-coal-composite. The literature has not measured this parameter for CGE models of China in a consistent nesting structure. We therefore borrow the corresponding CES parameter from GTAP-E, in which the value equals to 0.5. The non-coal composite is a CES composite of an oil-composite and a gas-composite. Similarly, in the absence of direct reference from the literature, we borrow the corresponding CES parameter from GTAP-E, in which the value equals to 1. The coal-composite is a Leontief composite of coal and coke, the oil-composite is a Leontief one of crude oil and petroleum products, and the gas-composite is a Leontief one of gas and gas supply.

Our electricity nesting structure is as the following. It is first a Leontief composite between power transmission and distribution and a power generation nest. This is a common setup as it is in GTAP-

E. The power generation nest, however, is new in the literature. This is partly because we have different sector classifications to those in the literature and is partly because we try to reflect some special characteristics of China's power system. Since the nesting structure is new, we do not have the corresponding CES parameter values from the literature. The scope of the current study does not allow us to conduct a thorough analysis regarding the value either. We thus begin by assigning values to the CES parameters in the main simulation scenarios based on our judgements regarding the relative difficulties of substitution in each decision level. We will then perform sensitivity tests regrading our judged values in alternative scenarios.

The power generation nest is first a CES composite of four parallel inputs, namely bioelectricity, hydropower, nuclear power and a 'main substitution' composite. This level of nesting reflects the fact that substitution among these four types of power generation technologies is difficult. The development of hydropower and nuclear power, in particular, is subject to geological and political constraints. We thus begin by assigning a relatively small value (0.5) to this CES parameter in the main simulation scenarios.

The 'main substitution' nest is a CES composite between the fossil fuel power nest and the wind and solar power nest. Obviously, this is where strong changes must happen to allow solar and wind power to replace fossil fuel power in order to achieve carbon neutrality. In addition to price incentives, laws and policies will be developed and implemented to make such changes easier. We therefore assign a relatively large value (1.5) to the corresponding CES parameter.

At the bottom of the electricity generation nest are two CES composites. The fossil fuel power composite is a CES nest of coal-fired power and gas-fired power, with a CES parameter value equals to 2. This reflects the fact that it is easier to change between coal and gas than it is to change between thermal power and wind power or solar power. The wind-solar power composite is a CES nest of solar power and wind power. Here we give a relatively small CES value (0.5) to reflect the intension to have strong developments in both power generation technologies. We do not want these two technologies become too competitive against each other.

Table 1: CES parameter values in CHINAGEM-E

	Value for non-energy sectors	Values for energy sectors
STHM	2	2
SGWS	0.5	0.5
SGMS	1.5	1.5
SELG	0.5	0.5
SNCC	1	0
SNEL	0.5	0
SENR	1.85	0.5
SGKE	0.72	0.72
SKEL	0.78	0.78

```
                                   x1tot(c,i)      TOTAL OUTPUT NEST
                                   / |   \
                                 /   |     \    <----- Leontief
                               /     |      \
                             /       |       \
                       KE-L-L  other cost  non-energy inputs
 VA-Energy nest          / | \                             /\
CES(SKEL) --->         /   |  \                           /  \  <------ CES
                     /     |   \                         /    \    Armington
                   /       |    \                      /       \
                Labor   Land   K-E composite      Domestic    Foreign
                                /\
                               /  \
                              /    \   K-E nest
                             /      \  <- CES (SGKE)
                            /        \
                           K          energy nest
                                             /\          Energy nest
                                            /  \ <--- CES (SENR)
                                           /     \
                                          /       \
                            non-Elec energy       Electricity
                                   /\                        /\    Elec nest
    Non-electricity energy nest   /  \                      /  \     <---Leontief
         CES ( SNEL) ->          /    \                    /    \
                               /        \                 /      \
                    NCoal-comp      Coal-comp       ElecDist    ElecGen
                         /|             /\                        /|\
                NCoal /   |   Coal nest/  \                     / /| \   ElecGen nest
         CES(SNCC)->/     |  Leotief->/     \                 /  / | \  <--- CES(SELG)
                   /      |          /       \              /   /  |   \
            Oil-comp     Gas-comp   Coal  Coking        bio, hydro, nuc   main sub
               /|           |\                                              / \
       Oil    /  |         |  \ Gas                                        /   \  main sub
   Leontief->/   |        |    \<-Leontief                                /     \   <-CES(SGMS)
             /   |       |      \                                        /       \
        Oil   Petrol   Gas   GasSupply                                 FF         WS
                                                                      /\          | \
                                                         ElecTherm   / \          |  \ ElecWS
                                                    CES(STHM)--->   /   \         |   \ <-CES(SGWS)
                                                                   /   \          |    \
                                                           ElecCoal   ElecGas   wind   solar
```

Figure 1: Multi-level fuel-factor nesting structure in CHINAGEM-E

3.4 Carbon pricing mechanism

A carbon price is a specific tax. It collects a given amount of monetary value from a given amount of physical CO2 emissions. The I/O database is based on value. We need to translate the specific tax on CO2 emissions into ad valorem tax that is consistent with the model database. We apply the method used in Adams and Parmenter (2013) to implement carbon pricing mechanisms. This method has been widely applied in CGE modelling in China (*e.g.*, (Feng et al., 2018) and (Liu and Lu, 2015)).

3.5 carbon capture and storage (CCS) mechanisms

We add carbon capture and storage mechanisms to this version of CHINAGEM-E. Reaching carbon neutrality without CCS would require carbon prices to be so high that fossil fuel use would become non-economically viable. With the help of CCS, however, the cost of reaching carbon neutrality would be significantly lower. We hence add two types of CCS mechanisms in this version of CHINAGEM-E, namely conventional CCS and BECCS (Bio-energy CCS). We identify four broad sectors, namely chemicals, cement, steel, and thermal power, to have conventional CCS installations. Such installations can be further distinguished between coal-, oil- and gas-based facilities. BECCS are only installed on bio-electricity stations.

Our CCS and BECCS mechanisms do not require the disaggregation of existing sectors. In the case of CCS, we assume a given percentage of carbon dioxide emissions are removed by CCS technologies. At the same time, we assume a give cost for per unit of CO2 removed. In the case of BECCS, it is a negative emissions technology. Biomass absorbs carbon from the atmosphere. When they are burnt, they release the carbon back into the atmosphere. This process is carbon neutral. If the carbon is captured and stored, however, they become negative emissions. Hence BECCS efforts should benefit from emissions permit sales. Thus, instead of assigning specific costs, we assume the costs of BECCS efforts equal to the benefits of permit sales.

Although we also feature DACCS in our scenarios, we treat them as residuals. That is, the remaining CO2 emissions after CCS and BECCS are all assumed to be removed by DACCS. Similar to BECCS, we assume the costs of DACCS efforts equal to its benefits from selling emissions permits.

4. Main scenarios

We set two main scenarios, namely the base-case scenario (BCS) and the carbon neutrality scenario (CNS). The BCS illustrates a likely economic development path before the carbon neutrality target was announced. It runs between 2017 and 2060. The BCS can serve as a benchmark to which results from the CNS are compared. The CNS illustrates a likely economic development path that would lead to carbon neutrality in China in 2060. It runs between 2021 and 2060. The deviations in results from BCS to CNS are thus the impacts of carbon neutrality efforts.

We give seven sets of assumptions in these two scenarios, they are:

1) Macroeconomic
2) energy production, consumption, and trade
3) carbon price levels
4) energy efficiency
5) energy preference
6) CCS penetration rates and costs
7) a CO2 emissions path

In BCS, we give assumptions to sets 1) – 4). In CNS, we give assumptions 4) – 7). Although both BCS and CNS are given set 4) assumptions, some shocks are of different sizes between the two scenarios. This section describes the assumptions used in both scenarios. In Section 5, we will also show and discuss the design and results of some additional, comparative scenarios.

4.1 Base-case scenario

4.1.1 Macroeconomic assumptions in the BCS

We give exogenous, specific growth rates to selected macroeconomic variables in the BCS. The following principles are used in setting the macroeconomic shocks.

1) Using IMF's world Economic Forecast, the Chinese economy (real GDP) will grow at 1.85% in 2020 because of the impacts of COVID-19. Followed by a strong recovery in 2021 the economy will grow at a rate of 8.25%, then returns to its normal growth trend from 2022: real GDP will continue to grow strongly, but overall growth will slowly diminish.
2) The pattern of growth will favor consumption and consumption-related industries at the expense of investment and investment-related industries;
3) Import growth will exceed export growth; and
4) Growth in the service sector will exceed growth in the industrial sector and
5) Growth in the industrial sector will be higher than that in the agricultural sector.

Table 2: Base-case scenario: growth rate of real GDP, employment, GDP components and other variables (%, selected years)

Exogenously specified variables	2020	2021	2025	2030	2040	2050	2060
Real GDP	1.85	8.24	5.49	4.03	3.16	2.87	2.60
Employed persons	-0.39	-0.26	0.04	-0.81	-1.11	-1.26	-1.21
Household consumption	2.61	8.96	6.14	4.59	3.65	3.31	3.00
Investment	1.96	8.37	5.68	4.29	3.57	3.08	2.60
Exports	2.45	8.81	5.92	4.28	3.06	2.63	2.30
Model generated results							
TFP	-0.82	5.29	2.67	2.02	1.94	2.08	2.06
Capital stock	6.58	6.05	6.18	5.63	4.28	3.62	3.11
Imports	4.86	10.9	8.07	6.32	5.18	4.17	3.20
Agriculture	-0.40	4.98	2.52	1.17	0.56	0.65	0.90
Industry	0.62	6.88	4.26	3.05	2.36	2.18	2.07
Services	2.27	8.78	6.01	4.57	3.65	3.29	2.95

GDP = gross domestic product; TFP = total factor productivity

Sources: Growth of real GDP 2018 to 2019 from NBS; 2020 to 2025 from IMF World Economic Outlook; 2026 to 2040 referring IEA's World Energy Outlook. 2041-2060 are authors' assumptions. Employment data from Zuo et. al. (2020). Growth of household consumption, investment and exports are authors' assumptions.

The upper part of Table 2 shows the assumed growth rates of the real GDP, employment[9] and GDP components. These numbers are used as shocks to CHINAGEM-E under the forecast closure. The lower part Table 2 shows the endogenously generated macroeconomic results of the BCS, including the growths of total factor productivity (TFP), capital stock, import and the growth of three macro sectors. Table 2 shows that with the declining employment because of rapid population aging, China relies on capital growth and total factor productivity improvement to sustain its economic growth.

4.1.2 Energy production, consumption, and trade assumptions in the BCS

We give exogenous shocks to four sets of energy-related variables in the BCS, including:

1) consumption of primary energy,
2) consumption of final energy,
3) production of electricity generation, and
4) energy import – quantity and price.

We consult IEA (2020) to formulate forecast assumptions for these four sets of exogenous shocks. For primary energy, we shock consumption of coal, oil, and gas. For final energy, we shock consumption of petrol, coke, and gas-supply. For electricity generation, we shock production of all eight types of power output. For energy import quantity and price, we shock coal and oil. These variables are chosen to be shocked annually due to the availability of forecasts for years between 2020 and 2040, in IEA (2020). IEA (2020) does not, however, have forecasts for years after 2040. The authors make their own assumptions based on many available information.

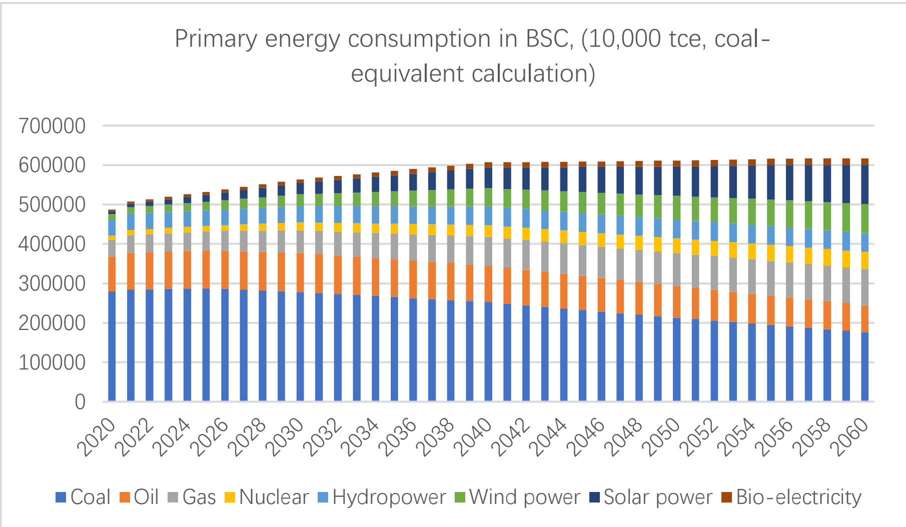


Figure 2: primary energy consumption in base-case scenario

[9]The growth rate of the exogenous variable employment is calculated based on the growth rate of working-age population and the aggregate labour force participation rate. In the baseline scenario, we assume that the aggregate labour force participation rate will remain at their 2015 levels until 2060. The growth rate of working-age population is from the medium variant of population projection conducted by Zuo et. al. (2020).

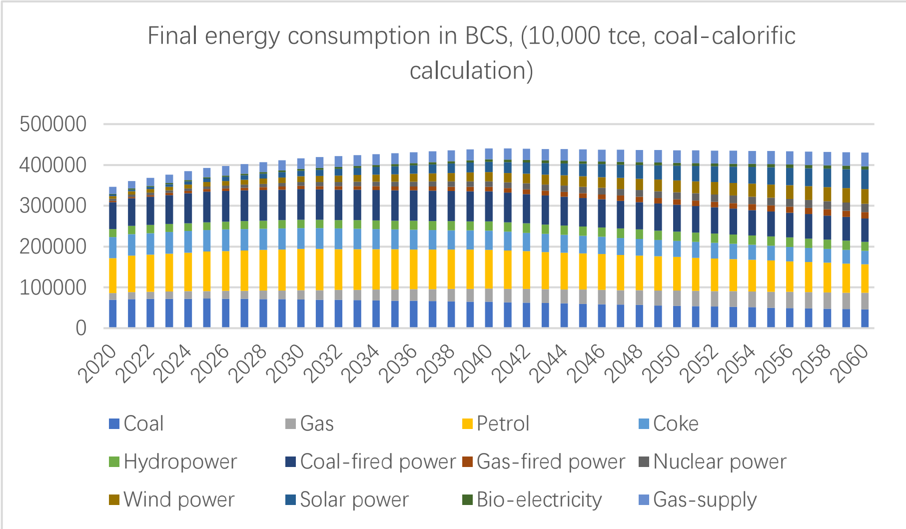


Figure 3: final energy consumption in base-case scenario

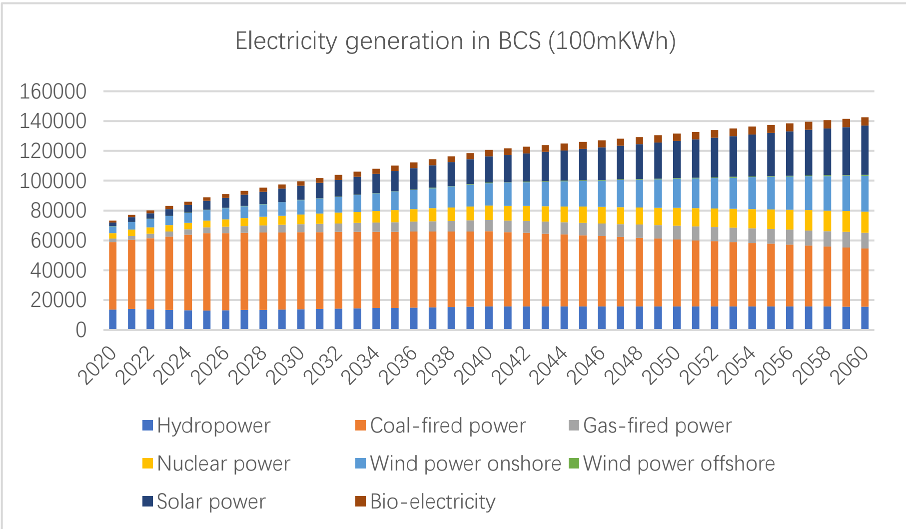


Figure 4: electricity generation in base-case scenario

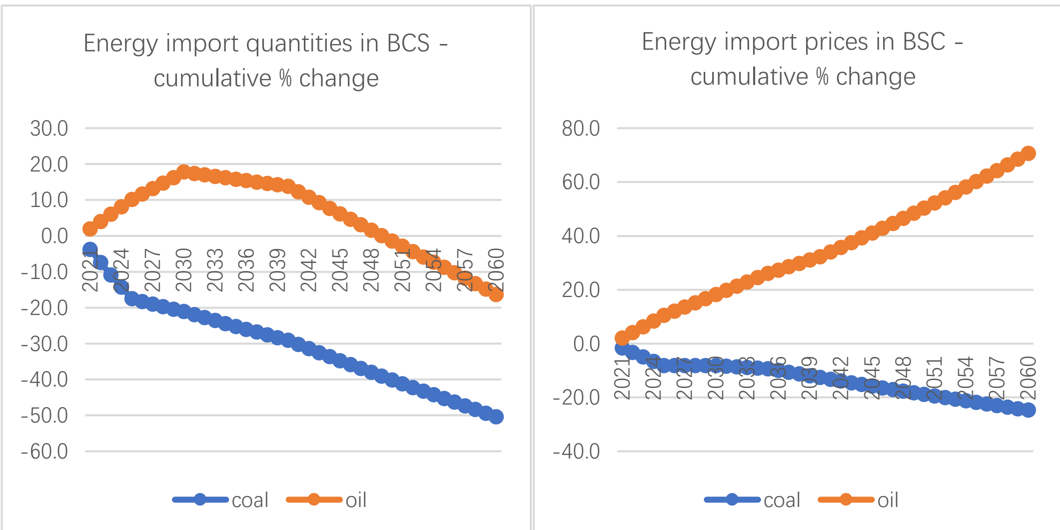


Figure 5: coal and oil import quantity and price changes in base-case scenario

The primary energy consumption of nuclear power, hydropower, wind power and solar power are endogenously generated, so are the final energy consumption of coal, gas, and all types of electricity, as well as total energy consumption levels. Figures 2-5 show base-case primary energy consumption, final energy consumption, electricity generation and energy trade, respectively. In our base-case scenario, total energy consumption increases gradually from 2020 (4875 mtce) to 2040 (6071mtce) and increases only slightly afterwards. By 2060, total primary energy consumption is 6171 mtce.

4.1.3 Carbon price assumptions in the BCS

We set carbon price levels for different years in the BCS. We consult IEA (2020) for years between 2020 and 2040, and we make our own assumptions for years between 2041 and 2060. Figure 6 shows carbon price levels in the BCS.

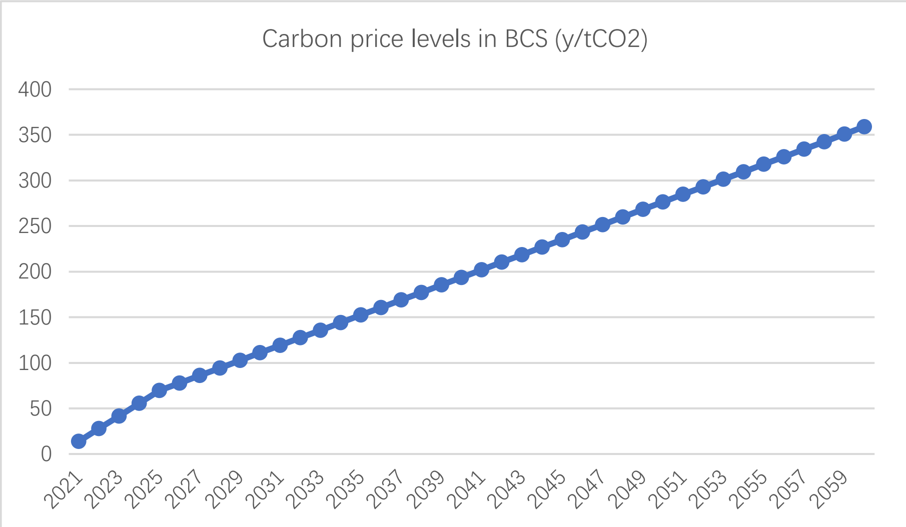


Figure 6: carbon price levels in base-case scenario

4.1.4 Energy efficiency assumptions in the BCS

Three sets of energy efficiency assumptions are given to the BCS, including:

1) Reduction in capital-using efficiency in renewable power generation
2) Changes in renewable power generation costs supplied to the grid
3) Energy efficiency improvement

Similar to our previous assumptions, we rely on IEA (2020) to formulate our shock sizes. The cos-neutrality condition is enabled in our energy efficiency shocks. Figures 7-9 show the levels of the shocks.

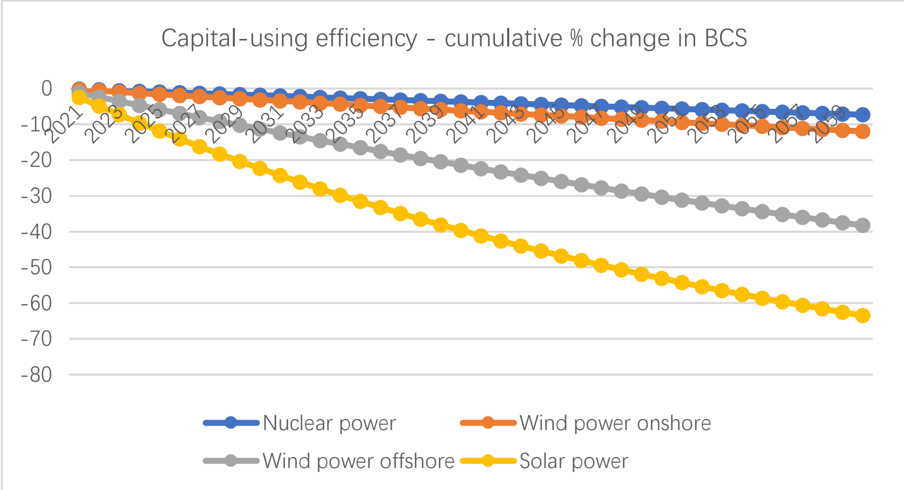


Figure 7: capital-using efficiency in base-case

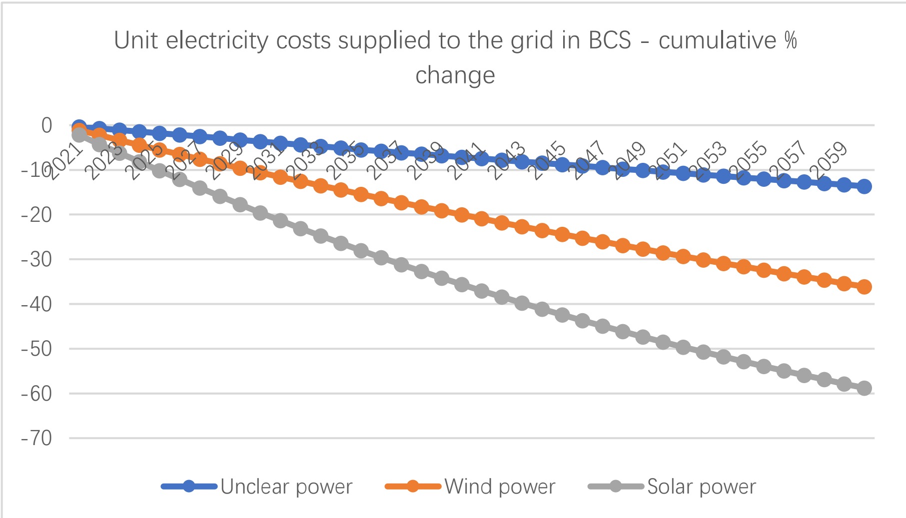


Figure 8: unit electricity costs supplied to the grid in base-case

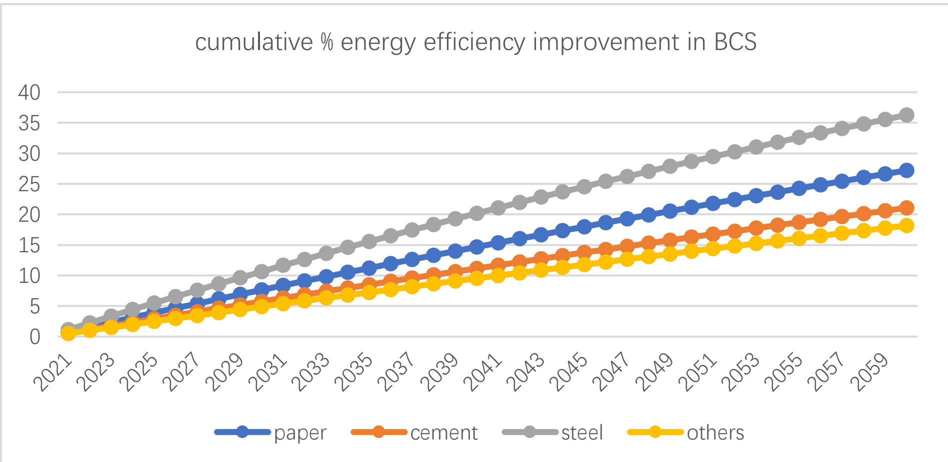


Figure 9: energy efficiency improvement in base-case

Source for Figures 2-9: IEA (2020) for years 2021 to 2040, authors' assumptions for years 2041-2060.

4.1.5 Emissions results in the BCS

Our base-case simulations can already produce some interesting results. The most important ones are CO2 emissions. Figure 10 shows that the absolute peak of CO2 emission occurs in 2025 at 10.5 btCO2 (billion tonnes of carbon dioxide). However, we can consider emissions reaches a plateau, or a 'flat peak' at 10.5 billion tons of CO2 between 2025 and 2030. Total emissions fall to 7.5 btCO2 in 2060. Clearly it requires a significant effort to reduce this to zero. The cumulative emissions in the base-case between 2020 and 2060 are 387 btCO2.

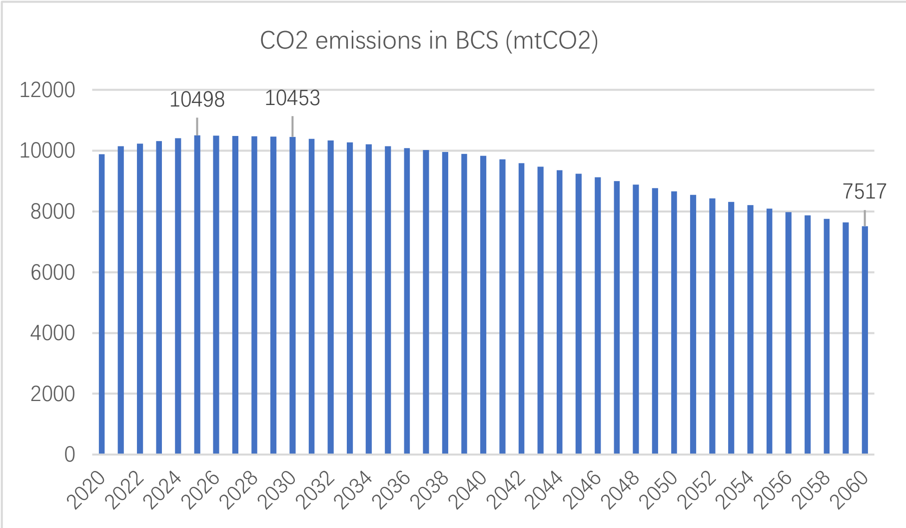


Figure 10: CO2 emissions endogenously generated in the base-case

Source: authors' simulation using CHINAGEM-E

4.2 Carbon neutrality scenario

In the carbon neutrality scenario (CNS), we make macroeconomic variables, energy production, energy consumption, energy trade and carbon price endogenous. We give extra energy efficiency shocks, energy preference shocks, and CCS shocks to the CNS. At the same time, we impose a path of carbon neutrality in this scenario. These settings would lead to higher carbon prices in the CNS than those in the BCS and put downward pressure to economic growth.

We also set some common macroeconomic assumptions. First, real wage is sticky in the short-run and becomes flexible in the long-run. Employment in the policy case can deviate from the base-case in the short-run but gradually gets back towards the base-case level in the long-run because of the lagged wage adjustment mechanism (Dixon and Rimmer, 2002). Second, capital stock is fixed in the short-run and is flexible in the long-run. Third, aggregate consumption follows household disposable income. Fourth, government expenditure moves together with aggregated consumption. Fifth, investment is a function of expected rate of return on capital. Sixth, export faces a downward-sloping demand curve. Seventh, import price is assumed to be fixed. Eighth, trade balance as a share of GDP is assumed to be fixed at the BCS level. Ninth, carbon pricing revenues are recycled as a lump-sum transfer to households. Tenth, the nominal exchange rate is set as the numeraire.

This subsection shows the extra, energy-related assumptions imposed in the CNS.

4.2.1 energy efficiency assumptions in the CNS

We give additional energy efficiency improvement in the CNS than they were in the BCS. The additional energy efficiency improvement kicks in from 2030 and gradually accelerates. The acceleration reflects the gradual increase in carbon prices, which stimulate the improvement of the energy efficiency. Energy efficiency improvements are unlikely to be cost-free. We, however, do not have specific information regarding the related costs. We thus assume energy efficiency improvements are 'cost-neutral'. The cost-neutrality condition is achieved by increasing other input costs across the board so that total costs are unaffected.

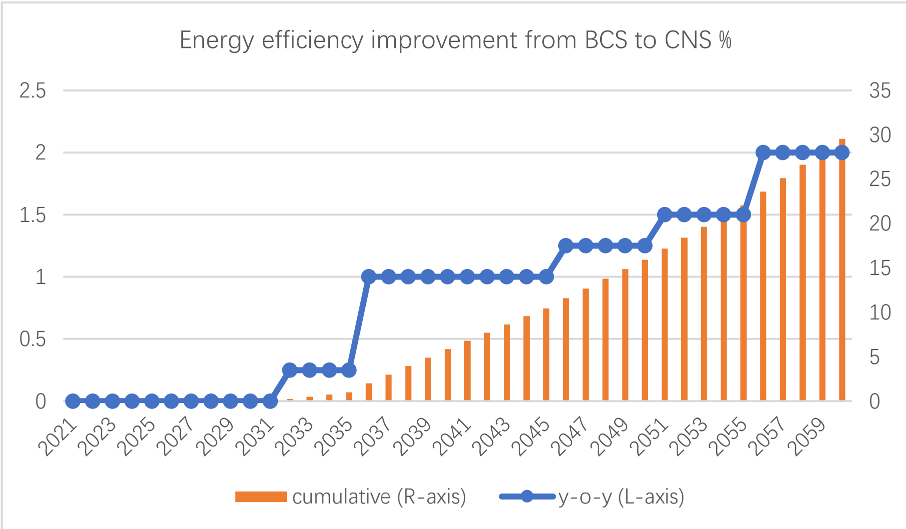


Figure 11: Energy efficiency improvement in carbon neutrality scenario

Source: authors' assumption

4.2.2 energy preference assumptions in the CNS

We explicitly model six types of energy preference change, namely:

A. households using electricity to replace fossil fuel,
B. buildings using gas to replace coal,
C. the transportation sector using electricity to replace petrol,
D. energy intensive industries using electricity to replace fossil fuel,
E. the grid using wind and solar to replace thermal power, and
F. the grid using gas-fired power to replace coal-fired power.

The shock levels resemble the reduction in demand for the fuels that are being replaced due to preference changes. Similar to cost-neutrality, energy preference shocks are assumed to be 'energy neutral', so that fuel replacements do not affect total energy use. Figure 12 shows the levels of the shocks. Notice that shocks A), D) and F) were given the same shock values and therefore only appear as a single line in Figure 12.

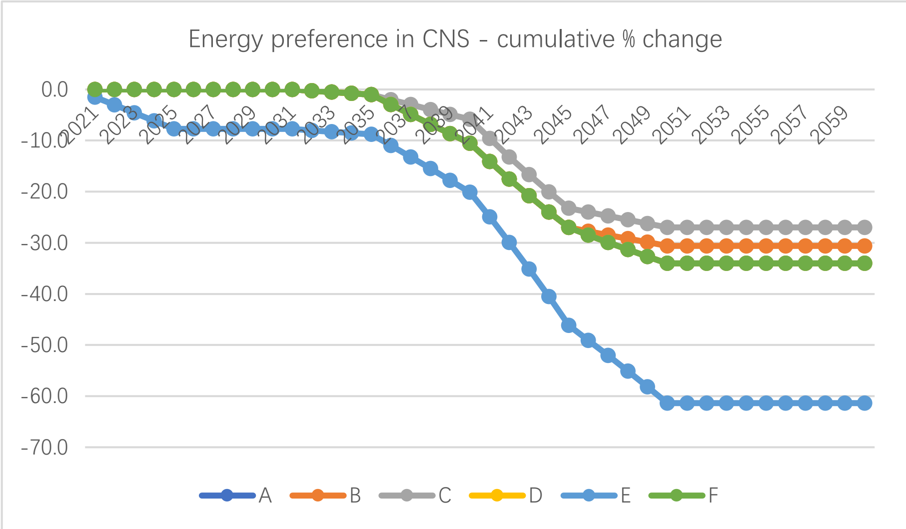


Figure 12: Energy preference assumption in carbon neutrality scenario

Source: authors' assumptions

4.2.3 CCS assumptions in the CNS

We explicitly model three types of CCS, namely fossil-fuel based CCS and bio-energy CCS (BECCS), and direct air CCS (DACCS). Fossil-fuel based CCS are utilized by four broad sectors, including chemical, cement, steel, and thermal power. Fossil-fuel based CCS are also distinguished by three fuel types: coal, oil, and gas. BECCS is only employed in the bio-electricity sector.

We choose to control the rate of penetration for CCS facilities. This would leave the amount of carbon dioxide emissions released by the five sectors to be endogenous. The actual amount of carbon dioxide emissions that are absorbed by CCS thus depends on the rate of penetration times the amount of actual emissions.

Figure 13 shows the rate of penetration assumptions. We assume coal-based CCS are utilized at large-scale from 2031. We set the penetration rate for coal-based CCS through our contacts from a large national energy enterprise. The penetration rate increases relatively quickly till 2050, when a large number of coal-based power generation stations reach their life-expectancy. The rate of penetration increases only slowly from 2051 and reaches 90% in 2060.

Oil- and gas-based CCS are assumed to be utilized in large scale from 2041. Their rate of penetration increases by a fixed annual rate that will lead it to reach 90% in 2060.

BECCS is also assumed to be employed in large-scale from 2041. Its penetration rate also increases by a fixed annual rate – one that will lead to be 80% in 2060. Notice that bio-electricity does not produce CO2 emissions in our database. In reality, however, BECCS do capture and store CO2 emissions. We use the level of bioelectricity to calculate the equivalent CO2 emissions from coal-fired power generation. We use this amount of CO2 emissions, together with our BECCS penetration assumptions, as the basis to calculate the amount of emissions reduced by BECCS.

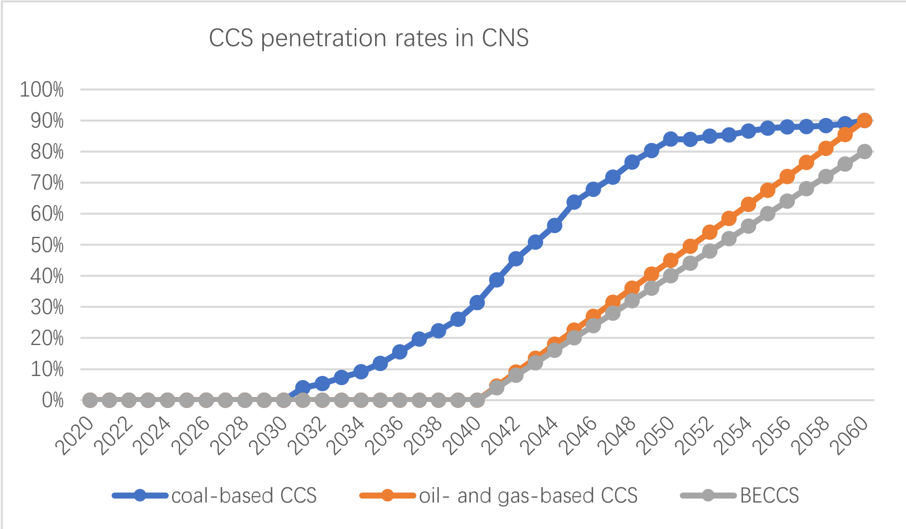


Figure 13: CCS penetration rate assumptions in the carbon neutrality scenario

Source: authors' assumptions

We also model the costs of employing fossil-fuel based CCS explicitly. We do this by assuming a fixed unit cost of 400 yuan per ton of CO2 emissions captured and stored by fossil-fuel based CCS. We do not model the cost of BECCS explicitly. We, instead, assume that the gain in selling CO2 permits offsets the costs of BECCS.

We assume DACCS becomes available in large scale from 2056. We exogenously set the amount of CO2 emissions that are taken by DACCS (see Figure 14). We also assume DACCS costs are fully compensated by its CO2 permits income.

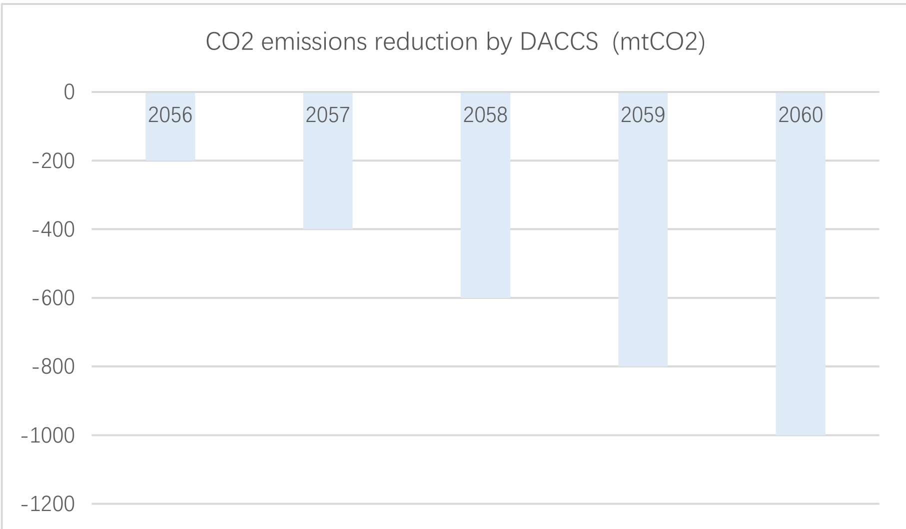


Figure 14: Emissions reduction by DACCS

4.2.4 The carbon neutrality path in the CNS

We impose a carbon neutrality path in the CNS that will lead total carbon dioxide emissions from fuel combustion to zero in 2060 (see Figure 15).

In this scenario, total CO2 emissions reaches its absolute peak in 2025 at 10.2 btCO2. Year-on-year emissions levels remain above 10 btCO2 in the 2020s. China aims to peak emissions before 2030. It seems an emissions peaking is indeed highly likely to happen before 2030. Peaking is of great significance to China as it marks a reverse in trend. In terms of total cumulative emissions in the long term, however, the actual year of peaking hardly matters – whether it is 2027 or 2029, the total emissions will be similar. In CNS, total cumulative emissions between 2020 and 2060 is 250 btCO2. This is 65% of total cumulative emissions in the BCS.

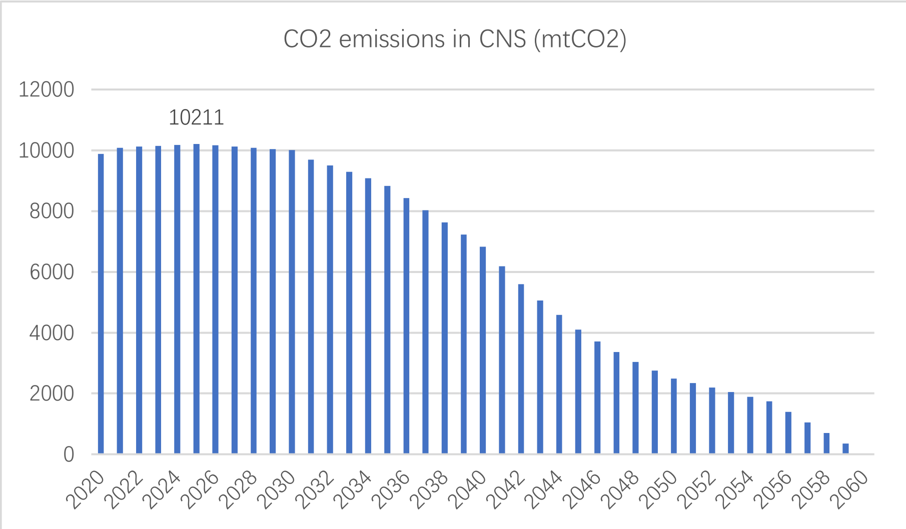


Figure 15: CO2 emissions in carbon neutrality scenario

Emissions begin to fall noticeably in 2031. Average annual emissions reduction rate between 2030 and 2035 is 2.5%. The fall accelerates from 2035. Average annual emissions reduction rate between 2035 and 2040 is 5.0%. It further accelerates in the 2040s, averaging 9.6% per annum. The 2040 is the fastest decade of emissions reduction largely due to contributions from fossil-fuel based CCS and BECCS. Although it slows down in the early 2050s, the reduction rate increases again in 2056 given large-scale adoption of DACCS.

5. Main scenario results

We show energy, macroeconomic and sector level results. Implications of simulation results will be discussed as well.

5.1 Energy results

5.1.1 Primary energy consumption and composition

Total energy consumption continues to rise in CNS from 2020 (see Figure 16). It begins to plateau in 2035 and peaks near 5800 mtce in 2040. It falls to just above 5500 mtce in late 2040s and stays near that level till 2060. Total energy consumption in CNS in 2060 is still higher than it is in 2020. This means it is possible to decouple energy consumption and CO2 emissions.

Total energy consumption in CNS between 2020 and 2060 is 228 btce – 95% of its BCS level. Hence, although the total energy consumption path is lower in CNS, cumulative energy consumption, as a percentage share, is not far below its BCS level. Nevertheless, the energy saving in absolute term, which mounts to 12 btce over 41 years, or 294 mtce per annum, is large.

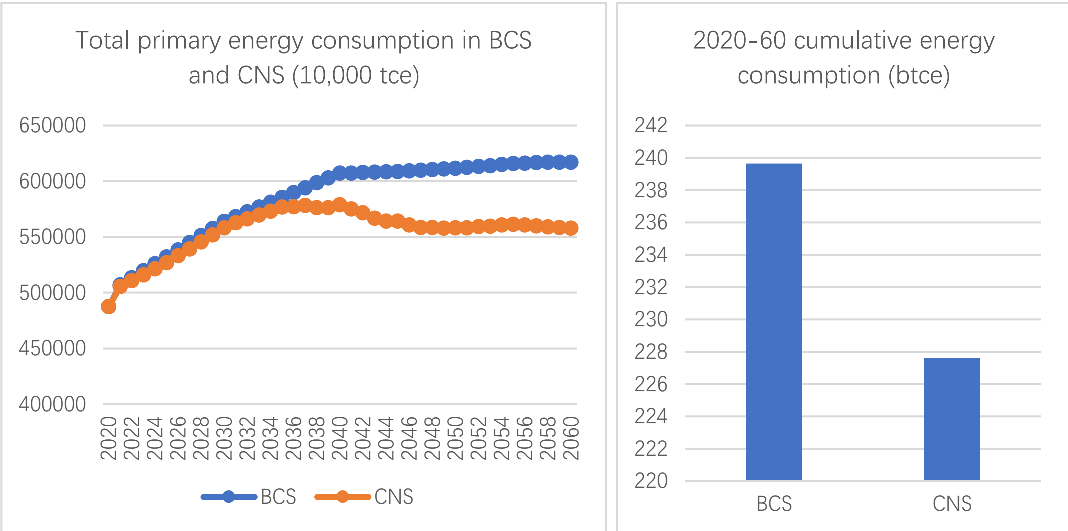


Figure 16: Total primary energy consumption

Source for Figures 16: authors' simulation with CHINAGEM-E

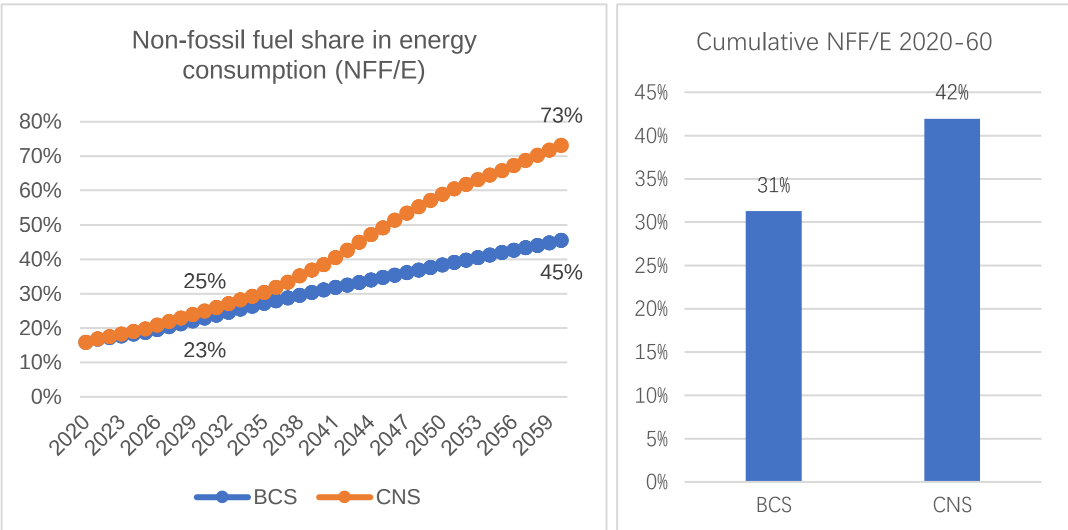


Figure 17: Non-fossil fuel share in energy consumption (NFF/E)

China aims to increase non-fossil fuel share in total energy consumption (NFF/E) to 25% in 2030. In BCS this share is only 23% (see Figure 17). In the CNS, however, the share just reaches this level. It shows that 25% target is consistent with a path towards carbon neutrality in 2060. That said, it is a challenge as it requires more mitigation efforts than those already exist in the base-case.

In CNS, NFF/E increases from 16% in 2020 to 73% in 2060. It is a 1.4 percentage points increase per annum. The share of cumulative non-fossil fuel in total energy consumption over the 41 years in BCS and CNS are 31% and 42%, respectively.

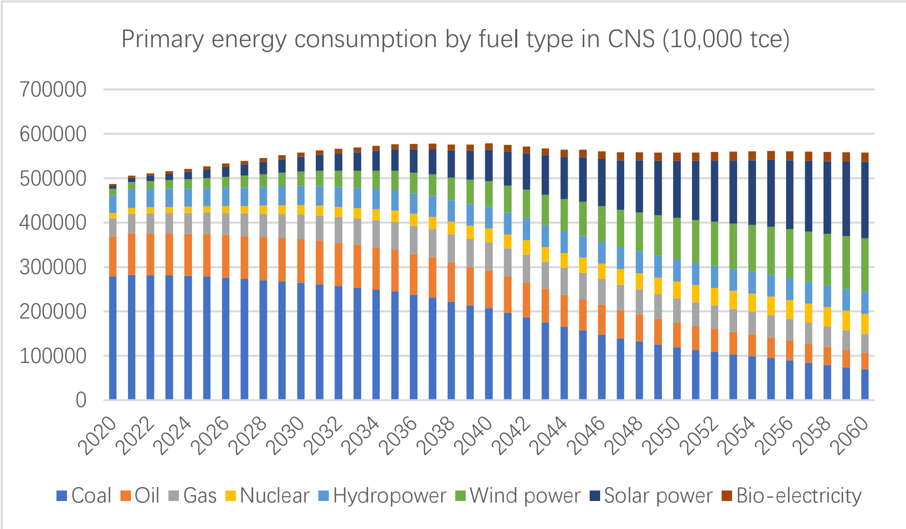


Figure 18: primary energy consumption by fuel type in CNS

We show primary energy consumption by fuel types in CNS in **Error! Reference source not found.**. Coal dominates the energy composition in 2020. It takes 30 years from 2020 for solar power to overtake coal and become the largest primary energy source in 2050. Only 4 years later, in 2054, wind power output also exceeds coal. Solar and wind power contribute the most to total energy use in 2060, accounting for 31% and 22%, respectively. Coal's share falls to 12%. In 2060, solar power and wind power output levels are not only higher than coal, but are also higher than their respective BCS levels, despite lower total energy consumption.

Figure 19 shows cumulative primary energy composition between 2020 and 2060. Coal is the largest primary energy source in cumulative term in both BCS and CNS. Adding energy consumption over the 41 years, coal accounts for 42% and 35% in BCS and CNS, respectively. In BCS, oil and gas are the second and third largest energy sources cumulatively, accounting for 15% and 12%, respectively. In CNS, solar power become the second largest, accounting for 14.5%. Oil is the third by 13.7%. Wind's share is still lower than oil's and is the fourth largest, accounting for 11%. Gas' share falls to the fifth, accounting for 10%.

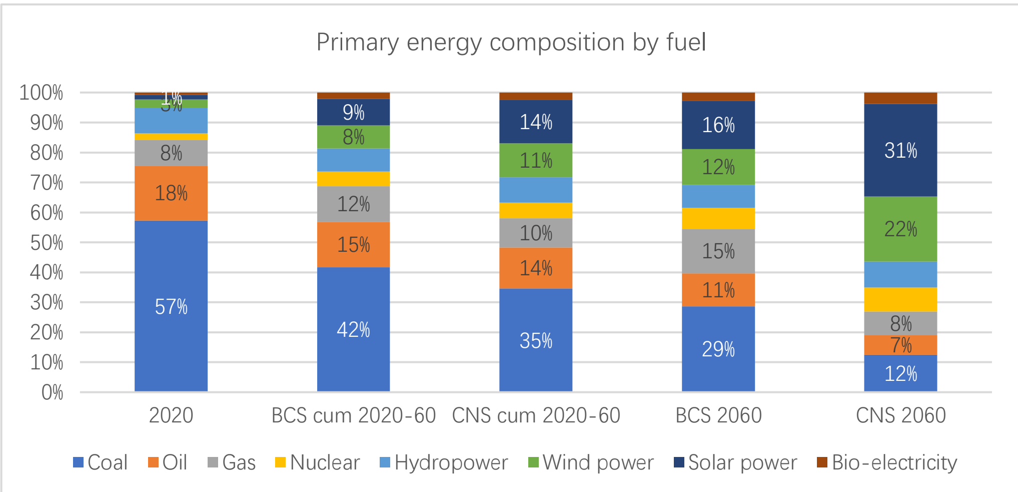


Figure 19: primary energy composition – a comparison between BCS and CNS

5.1.2 Electricity generation and composition

We compare total electricity generation in BCS and CNS in Figure 20. Electricity generation in CNS grows at a nearly constant rate over years, whereas it grows at a lower rate from early 2040s in the BCS. Hence electricity generation in CNS becomes noticeably higher than it is in the BCS from early 2040s and the gap expands afterwards. In 2060, electricity generation in CNS is 15.8 petawatt-hour (PWh) – 1.6 PWh more than it is in BCS. Cumulative electricity generation between 2021 and 2060 in BCS and CNS are 458 PWh and 477 PWh, respectively. Our simulations thus show that carbon neutrality could lead to higher electricity consumption because of the higher rate of energy preference.

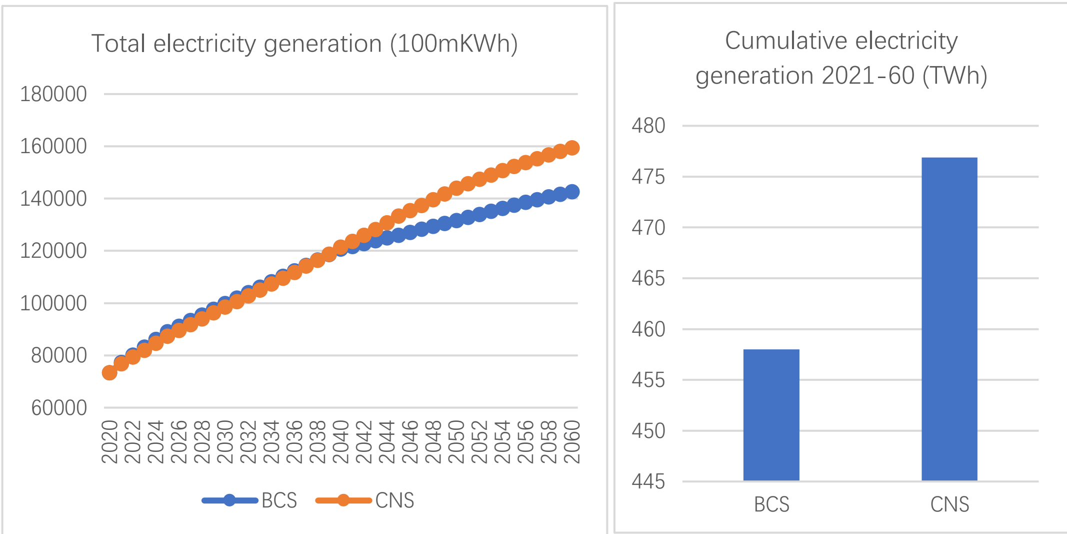


Figure 20: Total electricity generation

Electricity share in total final energy consumption (Elc/FE) keeps increasing in both BCS and CNS (Figure 21). The share of electricity in final energy increases at a roughly constant rate in BSC and reaches 48% in 2060. The share in CNS increases at a similar rate as it in BCS till mid-2030s and then increases faster in CNS. By 2060, the electricity accounts for 68% of total final energy consumption in CNS, this is 20 percentage points higher than it in BCS. Comparing with 2020, in CNS, the share of electricity in final energy increases 0.9 percentage points per annum. Cumulatively, Elc/FF is 40% and 46% in BCS and CNS, respectively.

The share of non fossil fuel based electricity generation in total electricity generation (NFF/Elc) increases in both BCS and CNS (Figure 22). From the beginning of the policy simulation, NFF/Elc increases faster in CSN than in BCS. By 2060, it reaches 65% and 85% in BCS and CNS, respectively. Between 2020 and 2060, in CNS, NFF/Elc increases by 1.2 percentage points per annum. Cumulatively, NFF/Elc is 40% and 51% in BCS and CNS, respectively.

We show electricity generation by fuel types in Figure 23. Coal-fired power dominates power generation in 2020. 62% of total power output is from coal-fired power generation in 2020. It takes 26 years from 2020 for solar power to overtake coal and become the largest source of electricity generation in 2046. Only 4 years later, in 2050, wind power output also exceeds coal-fired power. Solar and wind power contribute the most to total power generation in 2060, accounting for 36% and 25%, respectively. Coal-fired power's share falls to 11%.

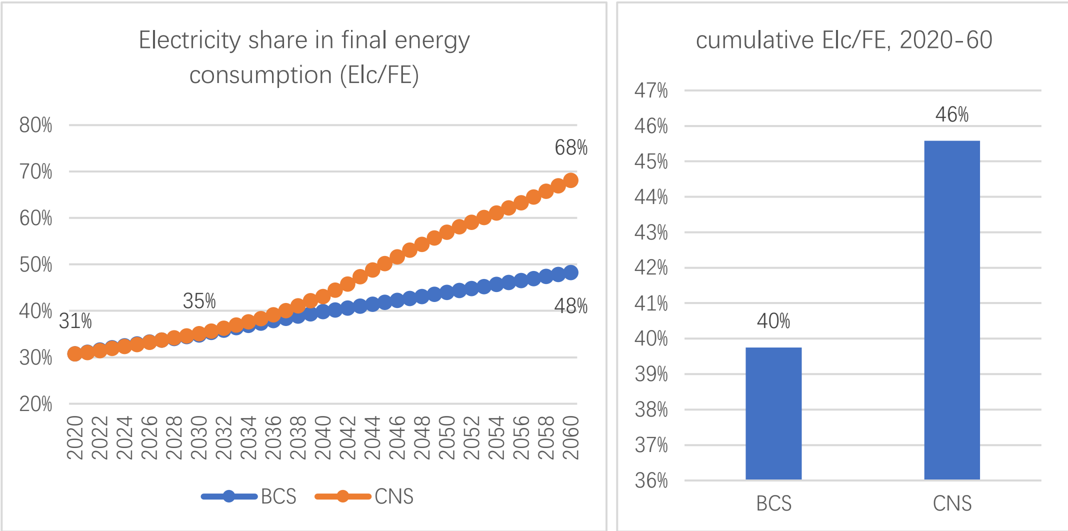


Figure 21: Electricity share in final energy consumption

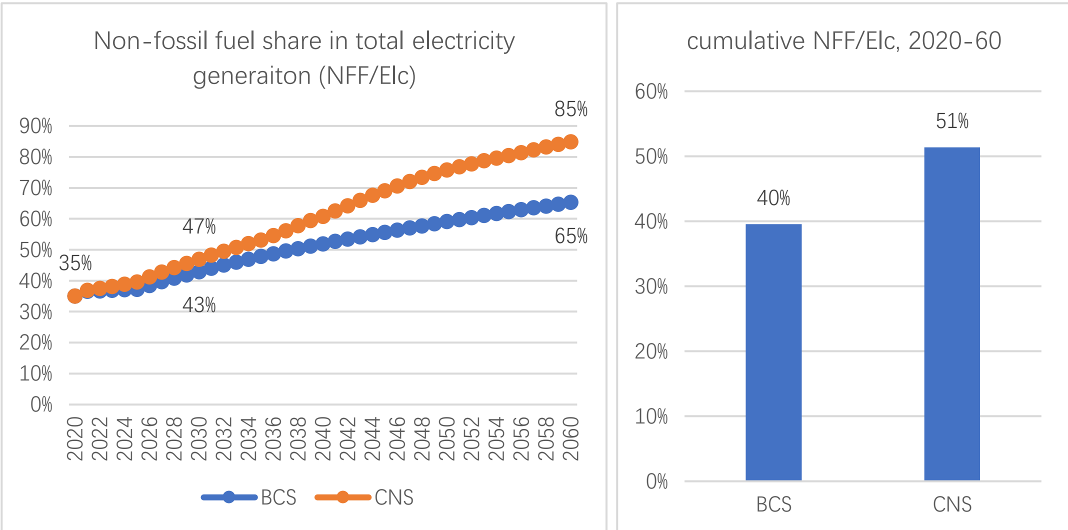


Figure 22: Non-fossil fuel share in total electricity generation

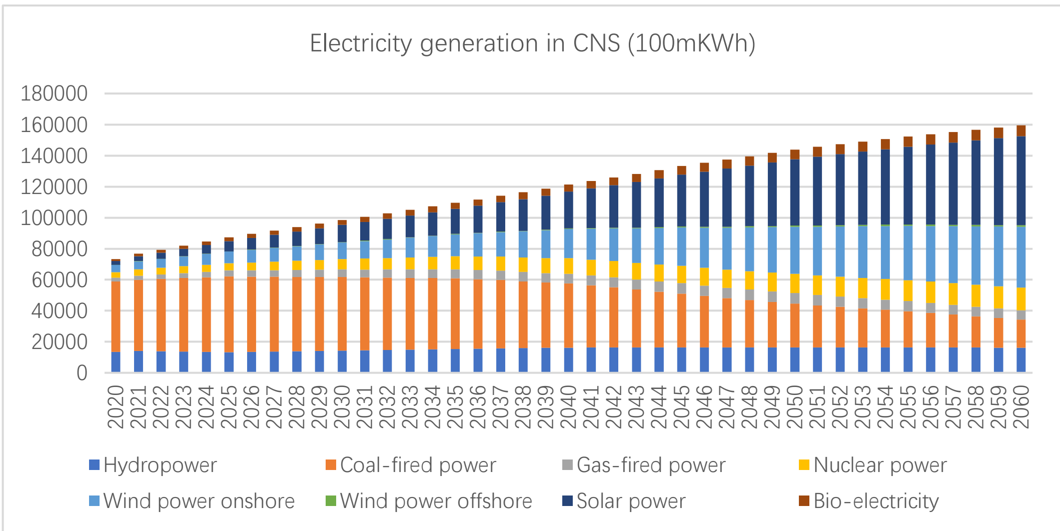


Figure 23: Electricity generation by fuel type in CNS

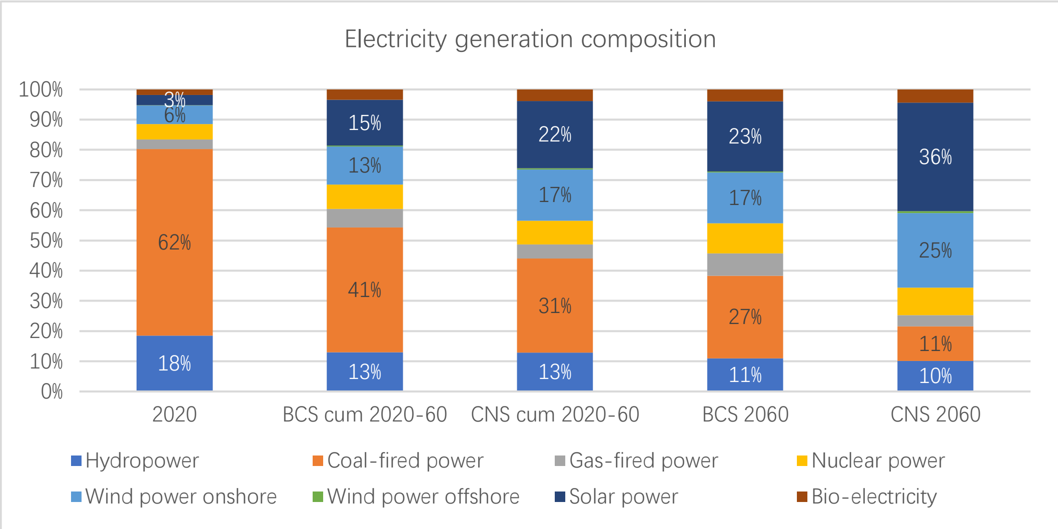


Figure 24: Electricity generation composition

Figure 24 shows cumulative electricity composition between 2020 and 2060. Coal is the largest primary energy source in cumulative term in both BCS and CNS. Adding electricity generation over the 41 years, coal-fired power accounts for 41% and 31% in BCS and CNS, respectively. Solar power is the second largest power source in both BCS and CNS cumulatively, accounting for 15% and 22% of total power output, respectively. In BCS, wind power and hydropower are equal third largest power sources, accounting for 13% to cumulative generation each. In CNS, though, wind power and hydropower account for 17% and 13%, and become the third and fourth largest power sources, respectively.

5.1.3 CCS-related results

Annual CCS and CO2 emissions results are displayed in Figure 25. Our simulations show that it is possible to achieve carbon neutrality while still having 3200 mtCO2 (million tonnes of carbon dioxide) emission in 2060. CCS, BECCS and DACCS will capture and store 1650 mtCO2, 550 mtCO2 and 1000 mtCO2, respectively.

The amount of CO2 emissions captured and stored by CCS peaks in 2048 at 2377 mtCO2, and then gradually falls. This is because there are less emissions to be captured by CCS facilities from fossil-fuel burners, especially those from coal-fired power generation.

Figure 26 shows the cumulative emissions and emissions reduced by CCS between 2020 and 2060. Over the simulation years, CCS, BECCS and DACCS reduced emissions by 49 btCO2, 5 btCO2 and 3 btCO2, respectively. These are equivalent to 17%, 2% and 1% of total emissions before being sequestrated by CCS, respectively. Our simulations thus show that CCS would help to reduce cumulative emissions by 20% (58 btCO2) over the simulation years.

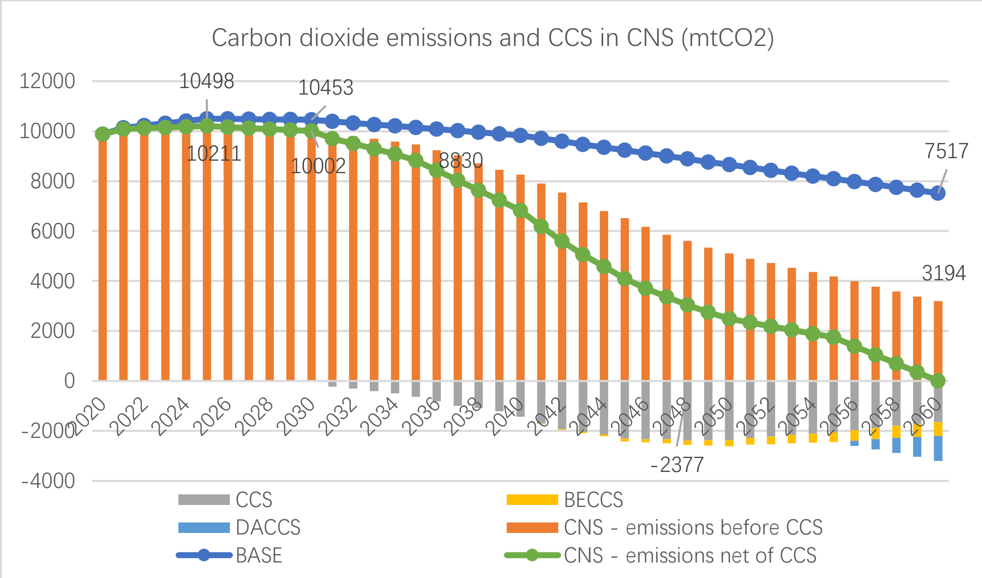


Figure 25: CO2 emissions and CCS in CNS

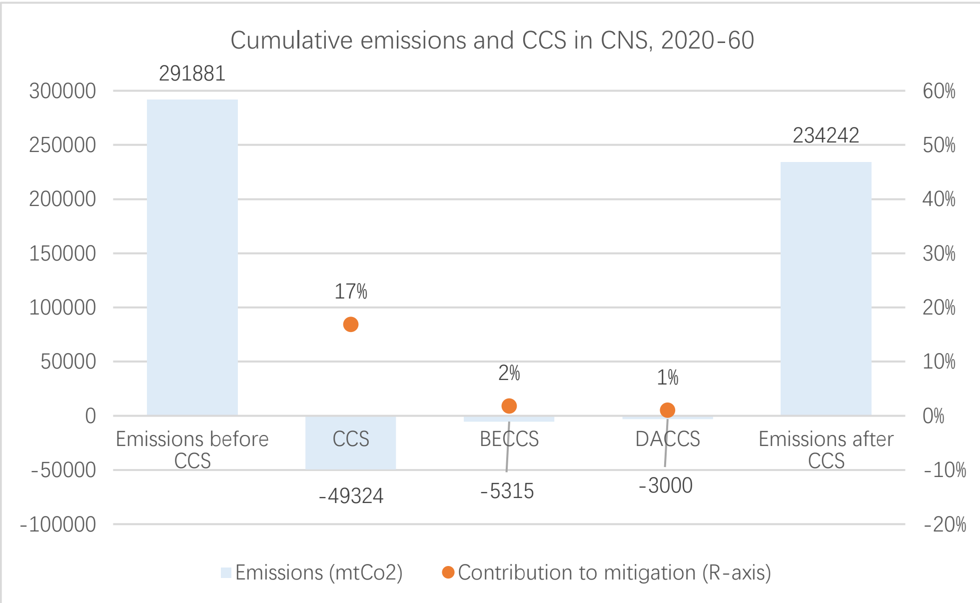


Figure 26: cumulative emissions and CCS in CNS

5.2 Economic results

5.2.1 Carbon price

We show levels of carbon price in Figure 27. In CNS, carbon price levels are slightly higher than those in BCS till mid-2030s. Before mid-2030s, extra CO2 mitigation in CNS are mostly achieved by changes in energy efficiency and preference. After mid-2030s, carbon price levels begin to increase faster in CNS. The acceleration is mainly due to the faster fall of total emissions in this period (see Figure 15).

Carbon price increases even faster after mid-2050s. Although the absolute levels of emissions reduction are smaller comparing with earlier years, the rate of emissions reduction are much faster in this period. Moreover, there are much less room for emissions reduction in the later years. The increase in CCS penetration rate also decelerates in the 2050s. These make marginal abatement costs to increase faster. By 2060, carbon price level reaches 1614 CNY per tonne of carbon dioxide in CNS.

Carbon price levels in CNS imply the level of efforts needed to achieve our carbon neutrality path. By 'imply', it shows that the carbon price levels are results endogenously generated in CNS. By 'efforts', we mean that they indicate the levels of price incentives for restriction on economic activities and motivation for fuel switch. Obviously, the higher the carbon price are, the lower the incentive to engage in energy-intensive activities and the higher the incentive to switch to cleaner energy sources. These levels of efforts themselves are not enough to achieve the carbon neutrality path though, they must work together with our energy efficiency, energy preference and other assumptions in the CNS.

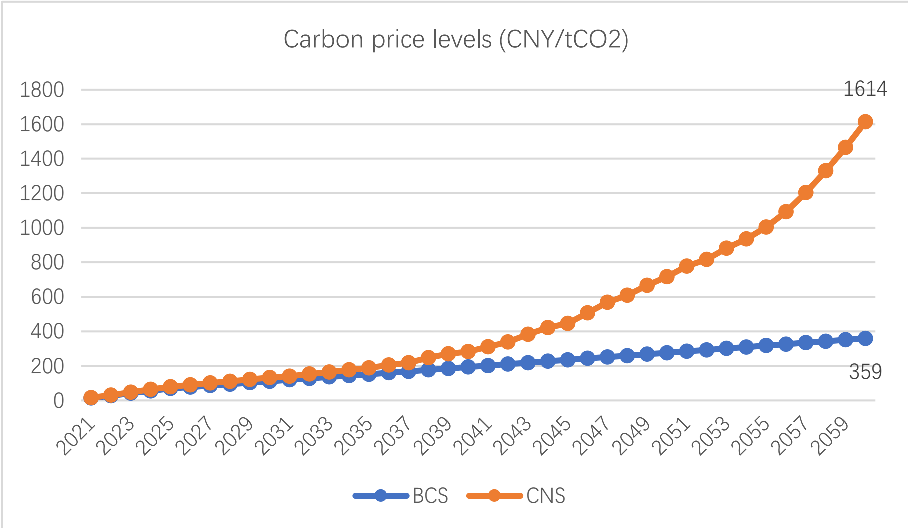


Figure 27: carbon price levels

Carbon price levels are results of the main shocks in CNS. They will increase the overall costs of the economy and especially the emissions-intensive industries.

5.2.2 Real GDP - supply side

Real GDP

Real GDP growth rates are close between BCS and CNS (see left graph of Figure 28). Between 2020 and 2060, real GDP grow by 313% and 308% in BCS and CNS, respectively. In 2060, real GDP in CNS will be 1.36% lower than it is in BCS (right graph of Figure 28). Notice that in CNS, in year 2035, real GDP will be 100.6% higher than it is in 2020. This suggests that China can achieve the target of doubling GDP between 2020 and 2035 and reaching carbon neutrality in 2060 at the same time.

Real GDP in CNS falls further below its BCS levels from late 2030s). This is the result of faster carbon prices increase in CNS. As we explained before, carbon price is a form of indirect tax that increases general costs of the economy and puts downward pressure on economic growth.

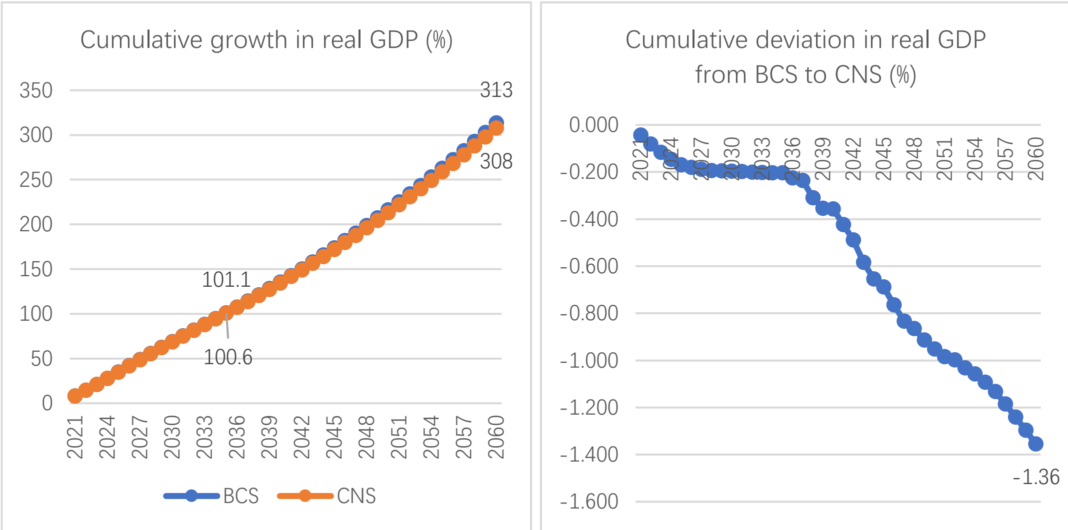


Figure 28: Real GDP results

Employment

Employment in CNS measured in wage bill weights are below the BCS levels (see Figure 29). They are, however, not far below. This is because of the lagged wage adjustment mechanism in the policy simulation. Employment levels in the policy case (CNS) tend to return to their base-case (BCS) levels. This assumption is consistent with the non-accelerated inflation rate of unemployment (NAIRU) equilibrium state in the long run. Under downward pressure of increasing carbon prices, in the CNS, employment declines to below BCS level. However, the lagged wage adjustment mechanism makes the real wage levels in CNS keep falling below BCS levels. The falling real wage helps employment levels in CNS to move towards their BCS levels. By 2060, employment (measured in wage bill weights) is 0.1% lower than its BCS level, and real wage is 0.6% lower.

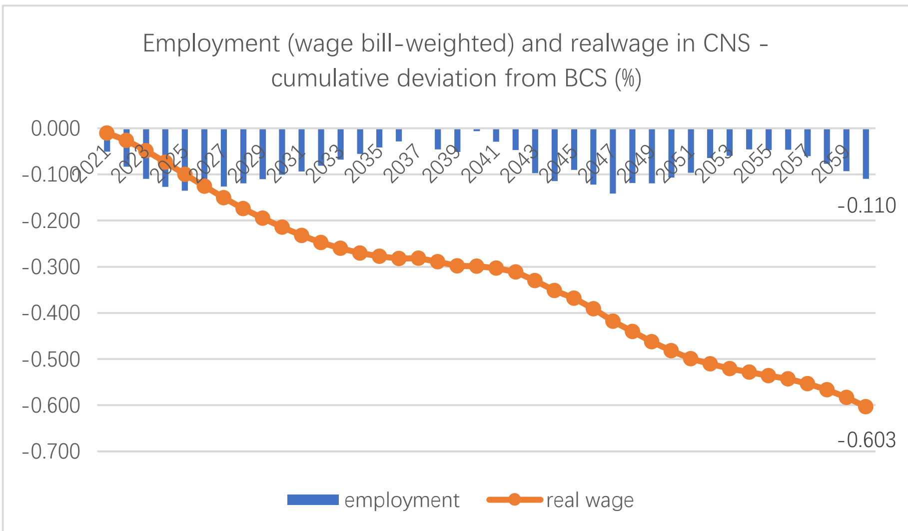


Figure 29: CNS employment (wage bill weighted) and real wage deviations from BCS

Figure 30 shows the number of employed persons at the national level. The difference in total number of employed persons between BCS and CNS is small. This is consistent with employment deviations measured in wage-bill weights. By 2060, the total number of employed persons are 502.1 million and 501.8 million in BCS and CNS, respectively. Carbon neutrality results 400,000 job loss in 2060 in CNS than in BCS. This, in an economy with more than 500 million employed persons, is a small reduction. Between 2021 and 2060, on average, the number of persons employed per annum are 660.7 million and 660.1 million in BCS and CNS, respectively. Hence the annual average number of unemployed persons that are attributed to CNS is 600,000, which, again, is small in comparison to China's work force.

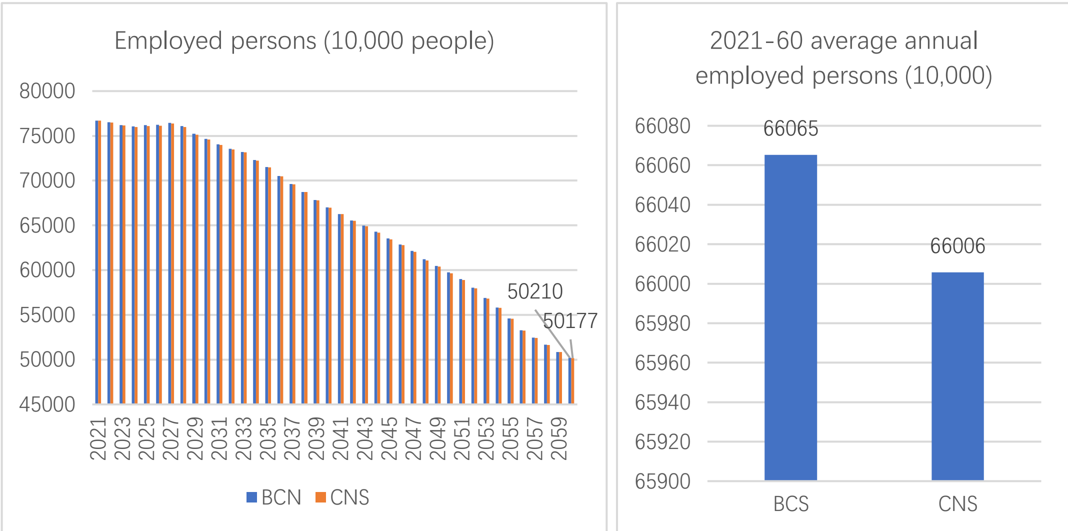


Figure 30: Employed persons – national level results

Capital

Figure 31 displays the capital stock changes. Capital stock movements are affected by output effects and substitution effects. The demand of the capital-energy bundle determines the output effect and the relative costs between capital and energy determines the substitution effect. In the early years, when carbon prices are low, the substitution effects dominate as overall demand for the capital-energy bundle are relatively less affected. In this phase, the contract in real GDP is small, and so are the contraction for the capital-energy bundle.

In addition, energy composition effects also help capital stock to be higher in the initial years. Recall that in BCS, the capital-using efficiency of nuclear power, onshore wind power, offshore wind power and solar power all improve. In the CNS, as the share of these energy outputs increase, the increase in capital-using efficiency has a higher contribution in enhancing overall capital-using efficiency and thus increase capital demand.

In the later years of the simulation (since late-2030s) output effects become dominate. Carbon price increases faster in late-2030s and real GDP falls faster during the same period. Fall in demand for the capital-energy bundle become dominate. In 2060, capital stock in CNS is 0.82% lower than it is in BCS.

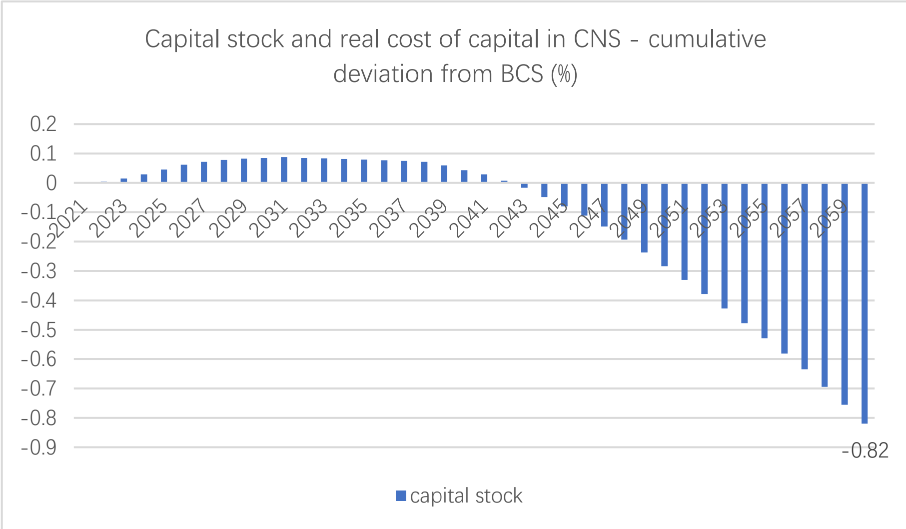


Figure 31: Capital stock and real return to capital in CNS

Supply side decomposition

Decomposition of real GDP deviations on the supply side is shown in Figure 32. From late 2030s, as carbon price levels increase, indirect taxes become the largest contributor to reduction in real GDP on the supply side. This is consistent with the simulation design, as carbon price changes are the main drivers to facilitate emissions abatement towards carbon neutrality.

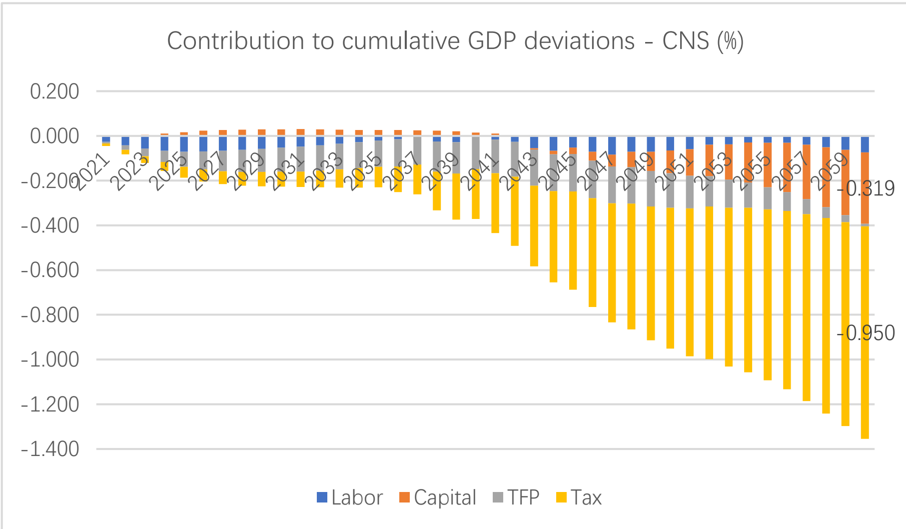


Figure 32: Real GDP deviations – a decomposition on the supply side

5.2.3 Real GDP - demand side

Demand side changes

The demand side GDP results are displayed in Figure 33. The changes of demand side components, namely consumption (including private and public consumption), investment, export, and import, are all consistent with real GDP movements in the early years of the simulation.

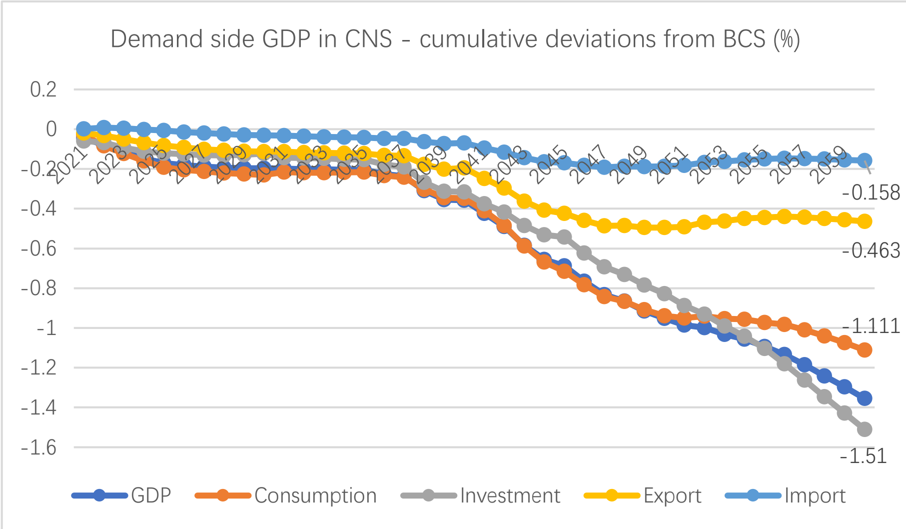


Figure 33: Demand side GDP results in CNS

Deviations become larger in late-2030s. The fall in consumption is less than the fall in real GDP. In 2060, consumption is 1.11% lower than it is in BCS. The transfer of carbon pricing revenues helps consumption to fall less than real GDP. Investment in CNS is 1.51% lower than it is BCS in 2060.

Higher carbon prices drive up domestic price levels which reduce domestic goods' competitiveness in the world market, resulting a lower export. The export is 0.46% lower in CNS than it is in BCS in 2060. Because in CNS trade balance as a share of GDP is assumed to be fixed at the BCS level, reduction in the export implies a reduction in the import. Import is 0.16% lower than it is in BCS in 2060

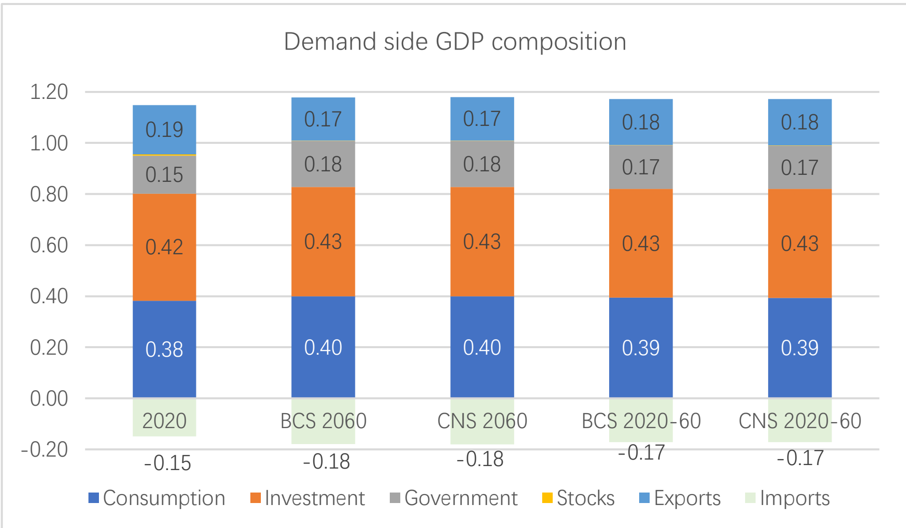


Figure 34: Demand side composition

We show demand side composition in Figure 34. The demand side structure is similar between BCS and CNS over the years. The share of private consumption increases from 38% to 40% between 2020 and 2060 in both scenarios. Over the 40 years, private consumption account for 39% of GDP, cumulatively, in both scenarios. Similarly, the shares for other demand side components are also stable. It thus suggests that the macroeconomic demand side structure is not affected by the carbon neutral goal.

5.2.4 Sector results

We show sector employment results at two different levels of sector classification – three macro sectors and 19 aggregated sectors. We show sector output results at two levels of sector classification – three macro sectors and 159 individual sectors.

Three macro sectors

Output and employment changes by three macroeconomic sectors are displayed in Figure 35. By 2060, real output of the industry sector is 1.51% lower than its BCS level. SRV (services sectors) and AFF (agriculture, fishing, and forest sectors) are 0.75% and 0.21% lower, respectively. The output reduction of the fossil fuel sectors, and fossil fuel intensive sectors are the main reason for the loss of the industry sectors.

In terms of losses in the total number of employed persons, however, SRV suffers the most. It loses on average 590,000 employed persons per annum. The changes in the total number of employed persons in AFF and IND roughly cancel out each other over the simulation years.

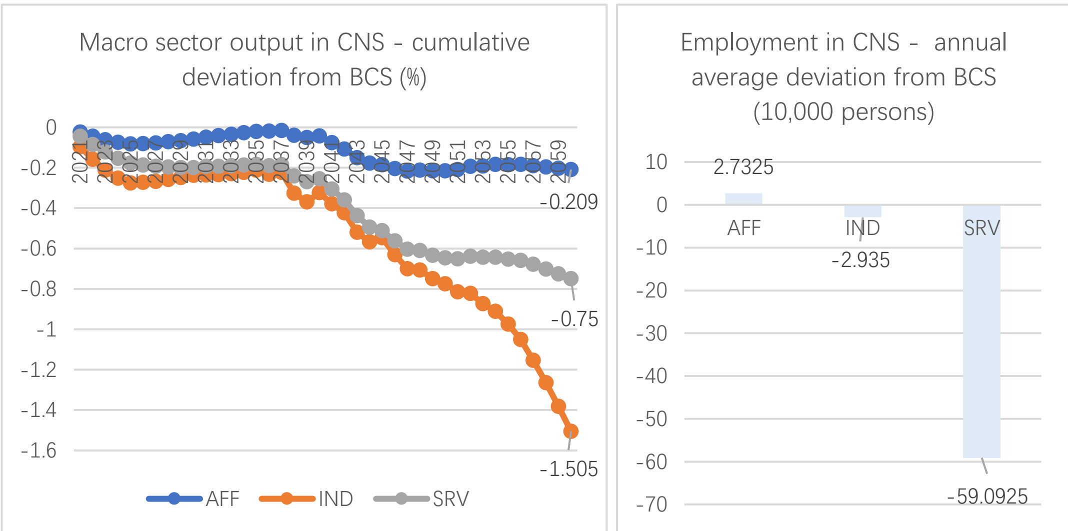


Figure 35: Macro sector output and employment results in CNS

19 aggregated sectors

Figure 36 shows changes in employed persons by 19 aggregated sectors. In 2060, the total job loss caused by carbon neutrality efforts are 340,000, among which the mining sector suffers the most job loss of 480,000. The ElcGasWater sector, on the other hand, employs 380,000 more people. It shows that despite the fall in coal-fired power output, the increase in solar and wind power sector would more than compensate the job losses in the coal-fired power sector. About half of the 19 sectors employ more people in 2060 in CNS.

Carbon neutrality efforts cause little changes to employment composition among these 19 aggregated sectors (see Figure 37**Error! Reference source not found.**). The employment compositions are almost identical between BCS and CNS. This indicates that even labors move among different sectors, the amount of movement is small in comparison to the total labor force – at least at the 19 aggregated level of classification.

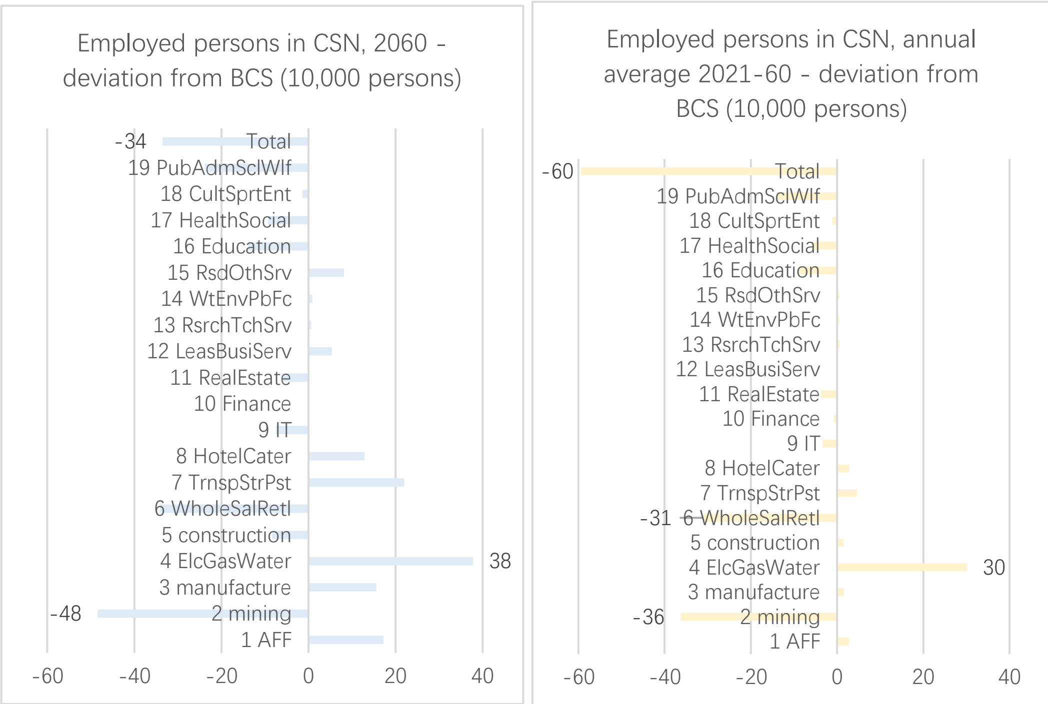


Figure 36: Employed persons in CNS by 19 aggregated sectors – deviations from BCS.

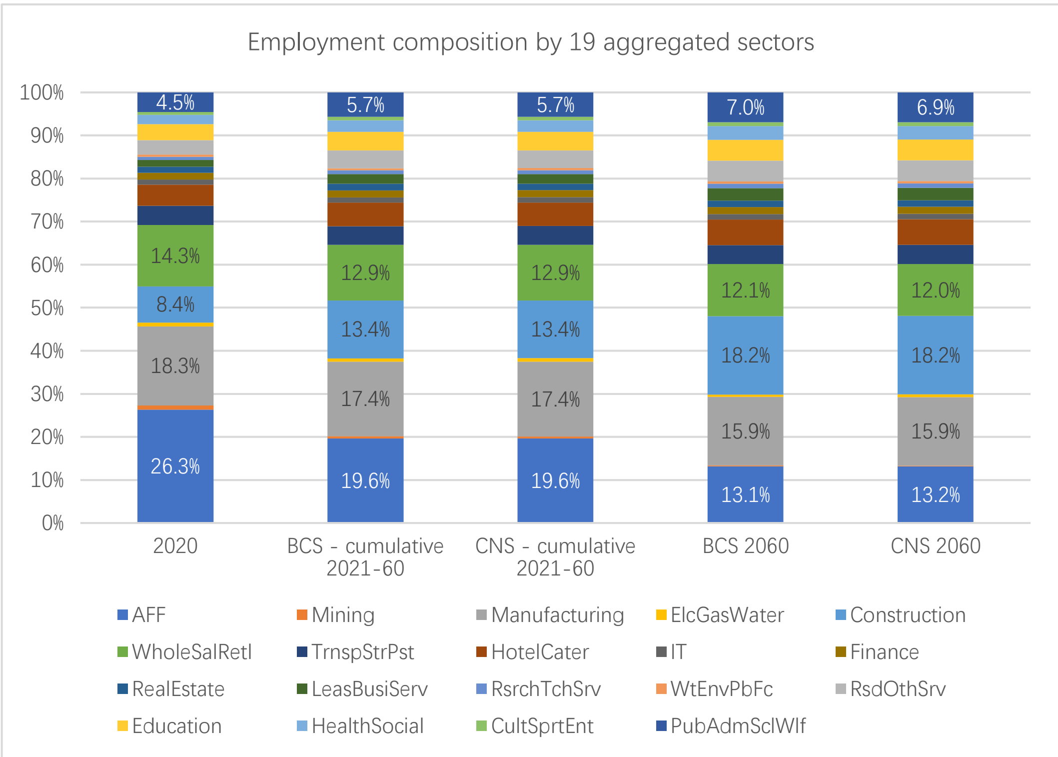


Figure 37: Employment composition by 19 aggregated sectors

159 individual sectors output

We show all individual sector output results in Figure 38. Clean energy and related sectors are, on the one hand, clear winners. Three clean energy sectors –wind offshore (Wind_Offsh), solar electricity (SolarElec) and wind onshore (Wind_OnSh) are standout winners. Three electricity-related sectors -bioelectricity (BioElec), electricity distribution (ElecDist), and power transmission equipment (PwrTrnEqp) can also be seen as clear winners. Fossil fuel energy and related sectors are, on the other hand, clear losers. Among which, coal (CoalMineProc) and coal-fired power (CoalElec) contract the most. Output changes of all other sectors congest in a small region and cannot be distinguished when results are presented at this level. We show non-energy sector output results in Figure 39. Deviations in 2060 are all within the -4%to 4% range.

A few generalizations can be made regarding sector output changes in the pursuit of carbon neutrality in China.

First, carbon neutrality mainly affects energy-related sectors. Clean energy sectors will gain at the expense of fossil fuel energy sectors.

Second, regarding upstream-downstream structures, sectors that sell a large proportion of output to electricity sectors (except fossil fuel electricity sectors) gain. This is because electricity output increase. The most notable case is the Power Transmissions Equipment (PwrTrnEqp) sector.

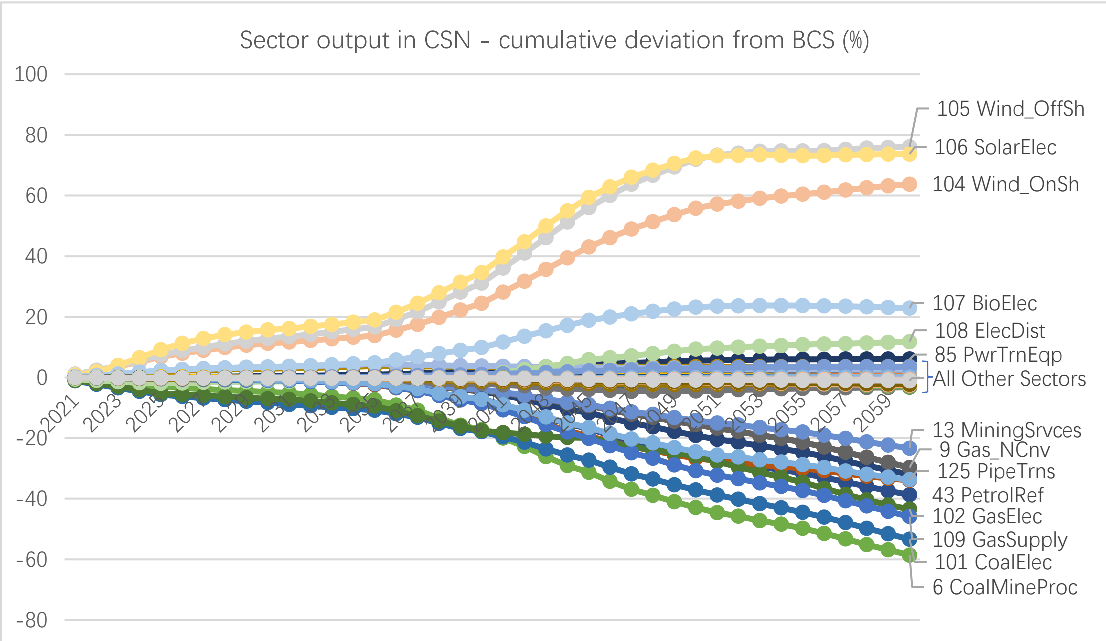


Figure 38: sector output results in CNS

Third, CCS helps carbon-intensive sectors to continue to produce. Basic Chemical (BasicChem), (Brick and Stone) BrickStone, and NMtlMinPr (Non-Metallic Mineral Products) are some of the most carbon-intensive sectors. One may expect these sectors' output to fall much more relative to less carbon-intensive sectors. The application of CCS, however, reduces the carbon emissions from these sectors. They thus do not have to pay the carbon pricing costs for the emissions that are captured and stored. This helps them to continue to produce.

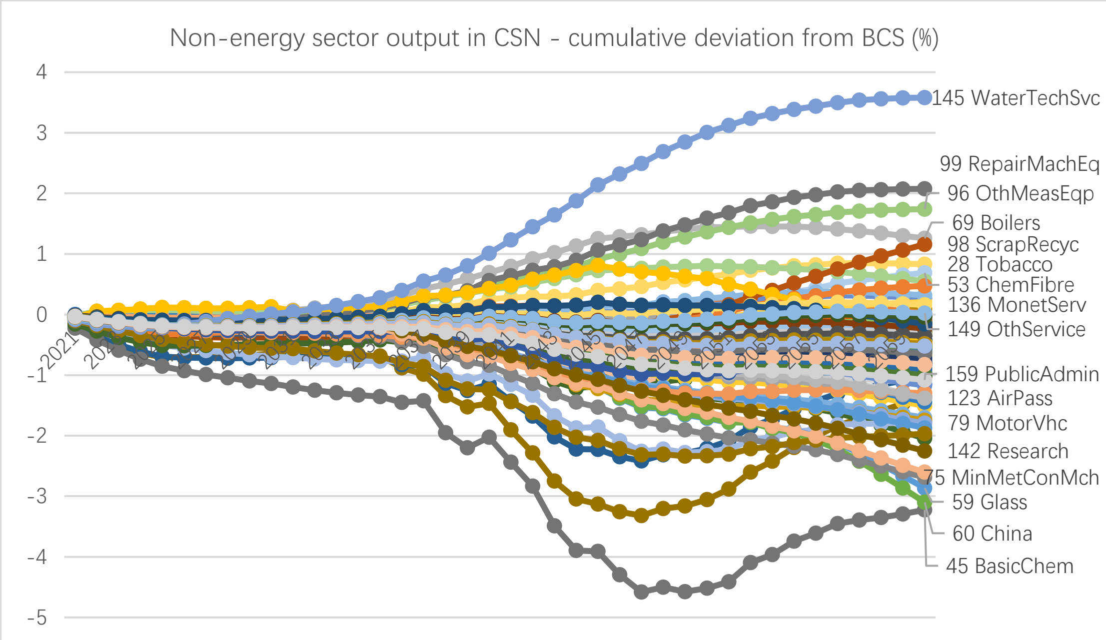


Figure 39: non-energy sector output results in CNS

Fourth, carbon-intensive sectors are affected negatively. Among non-energy sectors, BasicChem, China, and Glass contract relatively more than others do. These are carbon-intensive sectors despite their u/sage of CCS. Recall that CCS do not absorb all CO2 emissions, their penetration rates peak at 90% in our simulation years. Hence carbon-intensive sectors still release a portion of their emissions into the air and are therefore still subject to carbon prices. These costs will affect their output negatively.

Fifth, sectors whose costs compose more imported material suffer less. Here we refer only to non-energy sectors. Computers, communication equipment, and Electronic Parts are three large electronic sectors with high shares of import inputs. By 2060, the first two sectors' output fall much less than real GDP does from BCS, by 0.29% and 0.18%, respectively. The third sector's output increases from the BCS by 0.2%. These sectors suffer less from the higher domestic price levels caused by higher carbon prices as they rely more on imports, whose price are not affected by domestic carbon prices.

Sixth, investment-led sectors suffer more. Investment falls the most among final demand components as we showed in Figure 24. Sectors that sell a high share of outputs to investment demand thus tend to contract more. Residential Construction and Installation Construction, for example, are two sectors that sell the highest share of output to investment, whose real output fall by 1.4% and 1.9%, respectively, by 2060, both fall more than real GDP does.

Competitiveness of energy intensive goods

Carbon neutrality efforts affect domestic goods' international competitiveness. Higher carbon prices increase the general costs of domestic goods, especially energy intensive goods. This hinders these goods' price-competitiveness against their international counterparts.

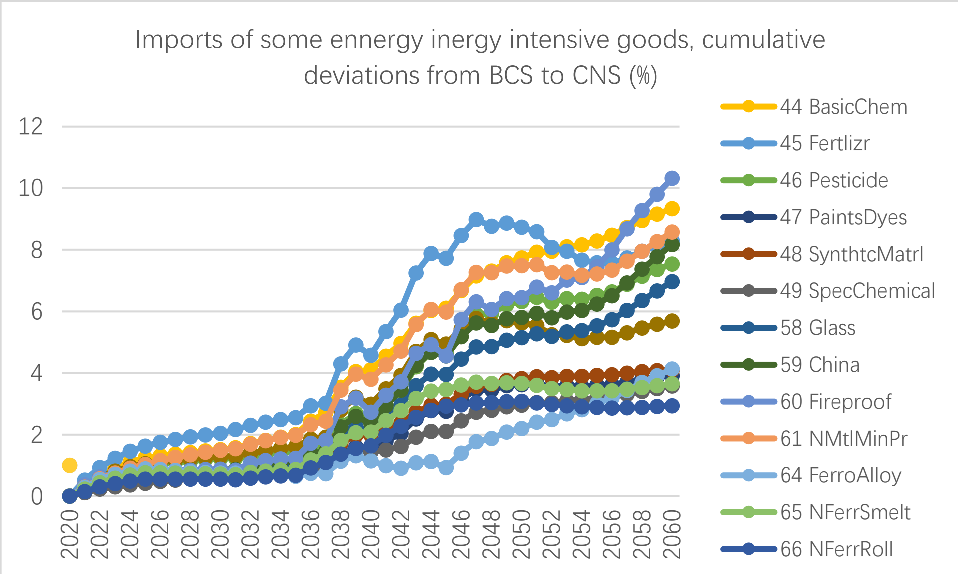


Figure 40: Energy intensive goods import volumes

Weaker price-competitiveness affect the trade of energy intensive goods. Figure 40 shows cumulative percentage deviations in import volumes from BCS to CNS. Volumes of energy intensive goods imports increase, despite lower domestic demand. For example, import demand for the basic chemical products is 9% higher in 2060 in CNS than they were in BCS and Import demand for fire proof products is 10% higher in 2060. This shows import substitution effects dominate even when demand for general energy intensive goods fall. Figure 41 shows cumulative percentage deviations in export volumes from BCS to CNS. Export volumes fall from the BCS levels because of the increased domestic prices of energy intensive goods.

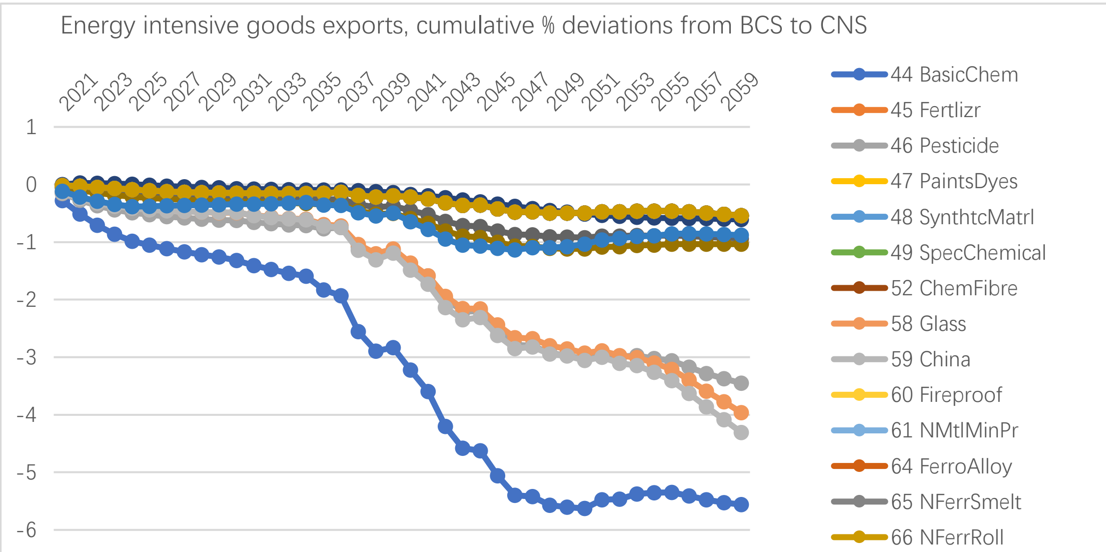


Figure 41: Energy intensive goods export volumes

Price competitiveness may not necessarily worsen should our underlying assumptions change. CNS assumes no changes in international prices. This assumption may not hold should global mitigation efforts increase world prices of energy intensive goods. Should global mitigation efforts not being able to drive world energy intensive goods prices up to China's levels, China might consider adopting boarder adjustment mechanisms to restore the relative prices. These alternative policy possibilities will be explored in Section 6.

Import demand for fossil fuel

We would like to point out that the substantial changes in China's energy structure as we discussed in the subsection 5.1 caused by the carbon neutrality action imply significant changes to its fossil fuel imports. China's import demand for coal, crude oil and gas will all fall sharply. By 2060, China's imports of coal and gas will be more than 60% lower and its oil imports will be around 50% lower than they were in the BCS (Figure 42).

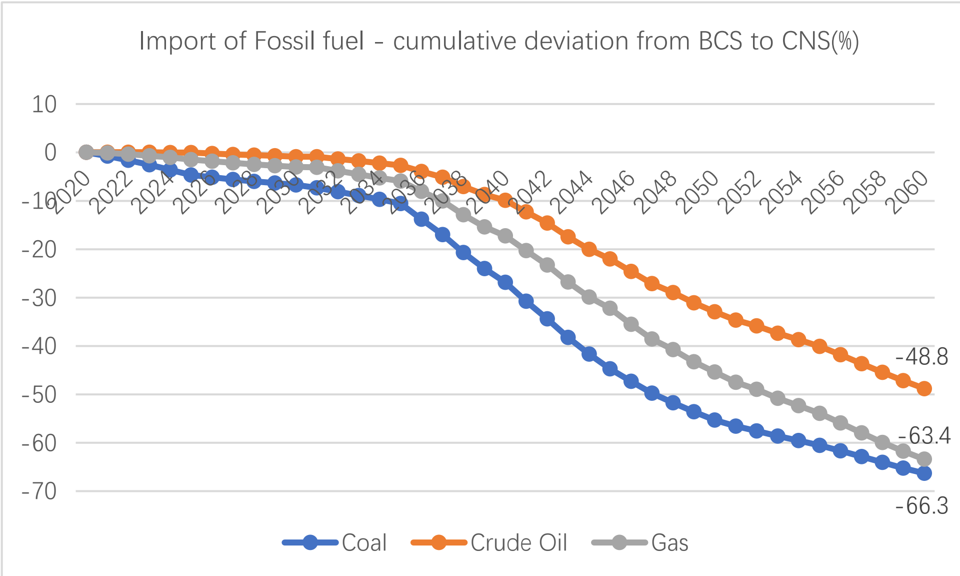


Figure 42: Imports of fossil fuel

5.2.5 Intensity targets

We show results against key policy targets in this sub-section. First, energy intensity of GDP (E/GDP) is shown in Figure 43. China has a target to reduce energy intensity of GDP by 13.5% from 2020 to 2025. Our simulations show that such a target is achievable in BCS and may even reach a 20% reduction in CNS. By 2060, energy intensity of GDP is 69% and 72% below its 2020 level, respectively.

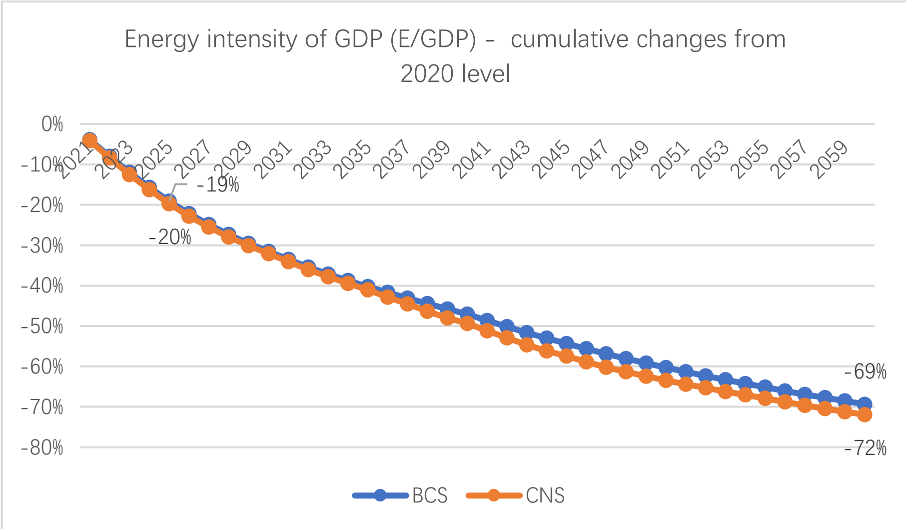


Figure 43: Energy intensity of GDP

Second, China aims to reduce emissions intensity of GDP (CO2/GDP) by 18% between 2020 and 2025, and it also aims to reduce CO2/GDP by more than 65% between 2005 and 2030. Our simulations show that in 2025, CO2/GDP is 21% and 23% lower than its 2020 level in BCS and CNS. In 2030, CO2/GDP is 68% and 69% lower than its 2005 level (Figure 44). Hence we can conclude that China is not only on course to reach its 2025 and 2030 emissions intensity targets but could exceed them by a reasonable margin.

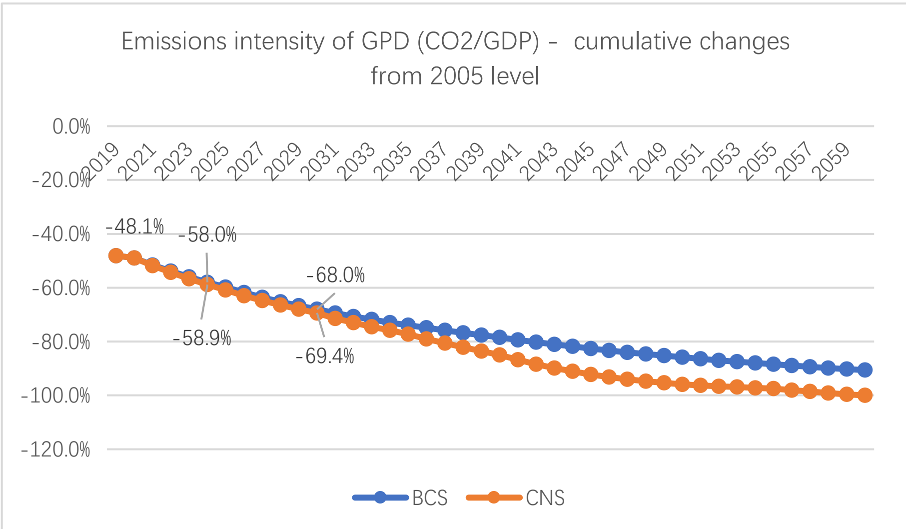


Figure 44: Emissions intensity of GDP

6. Alternative scenarios

We design fourteen alternative policy scenarios. All the alternative policy (AP) scenarios lead to carbon neutrality. The variations lie in their underlying assumptions.

6.1 the alternative scenarios design

The fourteen alternative scenarios are:

1) Earlier action scenario (EAS)
2) Labor tax cut scenario (LTC)
3) Higher efficiency and preference changes scenario (HEP)
4) Lower efficiency and preference changes scenario (LEP)
5) Higher CCS costs
6) Lower CCS costs
7) More DACCS contributions
8) Less DACCS contributions
9) Border Adjustment mechanisms
10) Global mitigation efforts
11) More elastic power substitution
12) Less elastic power substitution
13) All favorable conditions [2+3+6+7+9+11]
14) All unfavorable conditions [4+5+8+10+12]

AP1 - Early Action Scenario (EAS): First, we set a new carbon neutrality pathway such that China begins to reduce CO2 emissions at a faster pace from 2025. Figure 45 shows the net emissions paths for CNS and EAS. Earlier mitigation efforts would reduce total cumulative CO2 emissions, despite also just reaching carbon neutrality in 2060. This could potentially increase carbon prices and reduce real GDP.

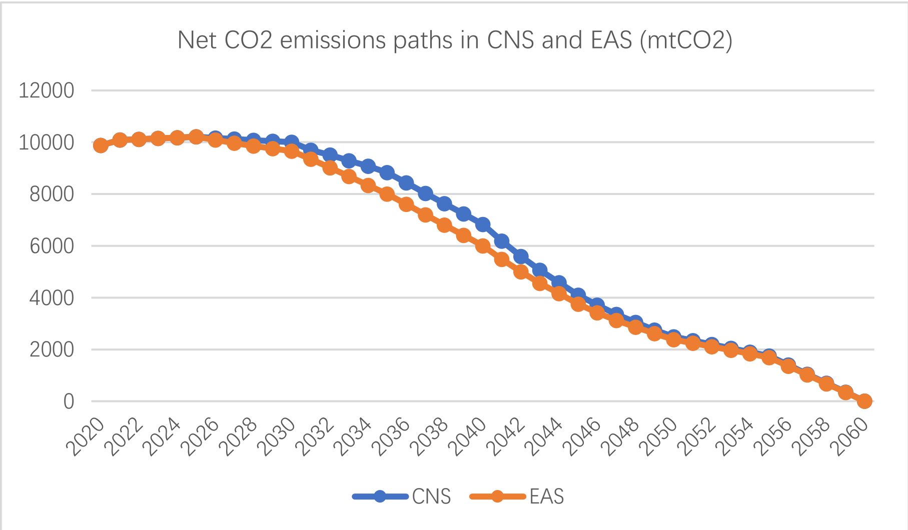


Figure 45: Net CO2 emissions in CNS and EAS

AP2 – Labor Tax Cut Scenario (LTC): In LTC we recycle carbon pricing revenues by cutting labor income tax. The literature suggests that replacing an existing, distortionary tax with an environmental tax may lead to efficiency gain than transferring environmental tax revenues in a lump-sum fashion (Bovenberg and de Mooij, 1994, Goulder, 1995). The LTC scenario is thus an experiment to examine the extent to which a tax swap between carbon price and labor tax contributes to economic growth.

AP3 & AP4 – Higher and Lower Efficiency and Preference Changes Scenario (HEP & LEP): Alternative scenarios 3 and 4 are designed to test the sensitivity of results with respect to changes in underlying energy efficiency and preference change assumptions. We increase all energy efficiency and preference change shocks by plus and minus 20% in AP3 and AP4, respectively. Further studies might investigate changes in individual energy efficiency and preference changes. Again, due to the scope of the analysis, we have only tested the combined changes. These will provide insights as to the ranges of results.

AP5 & AP6 – Higher and Lower CCS costs (HCC & LCC): In the absence of cost information, we assume unit costs of CCS abatement equals 400 yuan/t CO2 throughout the policy years. In AP5 and AP6, we increase and decrease the cost, each by 20%, respectively. These scenarios help us to gain insights as to the sensitivity of carbon neutrality costs to CCS costs.

AP7 & AP8 – More and Less DACCS contribution analysis (MDC and LDC): In MDC and LDC, we assume DACCS contribution to emissions reduction in 2060 to be 20% higher and lower than those in the CNS scenario, respectively. Therefore, in 2060, we set DACCS to reduce CO2 emissions by 1200 mtCO2 and 800 mtCO2, respectively. These two scenarios as set to test the sensitivity of results to DACCS assumptions, as the potential contribution to emissions reduction from DACCS can be uncertain.

AP9 – Boarder Adjustment Mechanisms Scenario (BAM): In this scenario we assume China implements import taxes on energy intensive imports (chemicals, cement, and steel) to maintain its domestic goods' price competitiveness. In our main simulation scenarios, import prices are assumed to be fixed and exogenous. China's carbon neutrality efforts increase the prices of its energy intensive outputs and reduce their price competitiveness globally. In this scenario, we continue to assume world prices are fixed but maintain domestic and import price ratios at the base-case levels by endogenizing the import tax rates. Mind that this is an experiment under the single-country model. Although a global model is arguably a better choice, it is beyond the scope of the current modelling setup. This experiment nevertheless helps to gain insights on potential implications of China implementing a boarder tax should global mitigation efforts are not up to China's levels.

AP10 – Global Mitigation Efforts Scenario (GME): In this scenario we assume that the world prices of the energy intensive goods (chemicals, cement, and steel) change by the same percentage points as China's domestic prices. This scenario hence is one way to assume that China's mitigation efforts are comparable to the world's mitigation efforts in terms of raising energy intensive outputs' prices.

AP11 & AP12 – More and Less Elastic Power Generation Substitution Scenarios (MES and LES): In MES and LES, we increase and decrease the values of the CES parameters for power generation nests by 0.2, respectively (see Table 3). As discussed in subsection 3.3, the values of the CES parameters for power generation nests in CNS are given by the authors in the absence of rigorous analysis. We therefore need to test the sensitivity of simulation results to these assumptions. A more detailed analysis could perform sensitivity test for every single CES parameter. Due the limitation of the space, though, we only try two scenarios with combined shocks to all four CES parameters.

Table 3: CES parameter values for power generation nests under CNS, MES and LES

	CNS	MES	LES
STHM	2	2.2	1.8
SGWS	0.5	0.7	0.3
SGMS	1.5	1.7	1.3
SELG	0.5	0.7	0.3

AP13 & AP14 – All Favorable and Unfavorable Changes Scenarios (AFC & AUC): AFC and AUC group all favorable and unfavorable changes together, respectively. The AFC combines the changes in AP2,3,6,7,9, and 11, as these scenarios all lead to higher real GDP than CNS does. The AUC combines the changes in AP4,5,8,10, and 12 as these scenarios all lead to lower real GDP than CNS does. Notice that AP1 is not included in neither AFC nor AUC as it simply is a different mitigation path. Although it leads to lower cumulative emissions it also reduces overall GDP. Hence it is not suitable to include it in neither the favorable nor the unfavorable group. The AFC and AUC scenarios thus offer the sensitivity tests to our assumptions overall.

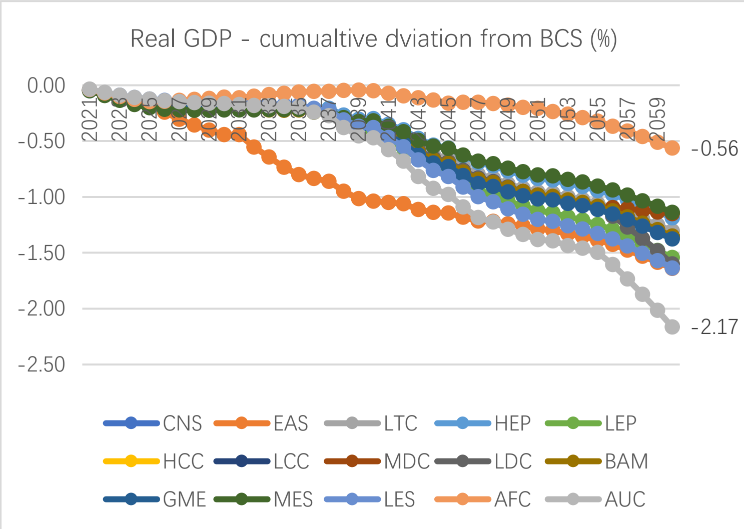
6.2 comparing CNS and alternative scenario results

Macroeconomic results

We show real GDP results of CNS and the fourteen alternative scenarios in Figure 46. Real GDP still fall below the BCS levels in all years. EAS leads to the fastest fall of real GDP level in the early years. This is a direct result of stronger mitigation efforts than all other cases, we will show this by cumulative CO2 emissions later. In 2060, LTC, HEP, LCC, MDC, BAM and MES lead to smaller reduction in real GDP than that was in CNS. Hence these were grouped as favorable changes. LEP, HCC, LDC, GME and LES lead to bigger reduction in real GDP than that was in CNS. Hence these were grouped as unfavorable changes.

The direction of the GDP results for the alternative scenarios comparing with the CNS are straightforward except for BAM and GME. In both BAM and GME, the price competitiveness for energy intensive goods between domestic and international outputs were assumed to be unchanged. This will lead to two effects in opposite directions. On the one hand, improved price competitiveness helps domestic goods against their foreign counterparts. On the other hand, overall costs to the economy are increased. The only difference between BAM and GME is that in BAM the international prices are fixed and import tax rates are changed, whereas in GME the international prices are changed but the import tax rates are fixed. Results show that in 2060, real GDP is 1.351% and 1.376% lower than the BCS level, respectively. Such results imply that when price competitiveness is restored without import taxes, the negative effects from the higher costs outweigh the improved competitiveness for domestic outputs, and therefore leads to lower real GDP than that was in CNS. When the price competitiveness is restored by higher import taxes, however, the added tax revenues compensate for the losses and therefore leads to slightly smaller reduction in real GDP than it was in CNS.

AFC and AUC show the combined results of favorable and unfavorable changes, respectively. Real GDP deviate from BCS by -0.56% and -2.17%, respectively. Such results show the extents to which real GDP changes may alter should underlying assumptions change, given the same net emissions path.



	Cumulative % deviations in real GDP, 2060	
	from BCS	from CNS
CNS	-1.355	
EAS	-1.639	-0.284
LTC	-1.303	0.052
HEP	-1.187	0.168
LEP	-1.543	-0.188
HCC	-1.356	-0.001
LCC	-1.354	0.001
MDC	-1.149	0.206
LDC	-1.600	-0.245
BAM	-1.351	0.004
GME	-1.376	-0.021
MES	-1.138	0.217
LES	-1.636	-0.281
AFC	-0.563	0.792
AUC	-2.165	-0.810

Figure 46: Real GDP in CNS and alternative scenarios

We then want to compare contributions of each alternative scenario to the overall GDP impacts in AFC and AUC. We first calculate the cumulative percentage deviations in real GDP in each alternative scenario from the carbon neutrality scenario (see Figure 46, right column in the table). We then add these deviations from each alternative scenario in AFC and AUC. We notice that when adding the contributions from each scenario, the totals are less than the absolute deviations in AFC and AUC. We call the residuals the policy combination effects (PCEs). The fact that the PCEs are in the same direction as the individual changes imply that when combined they tend to enforce rather than offset individual effects.

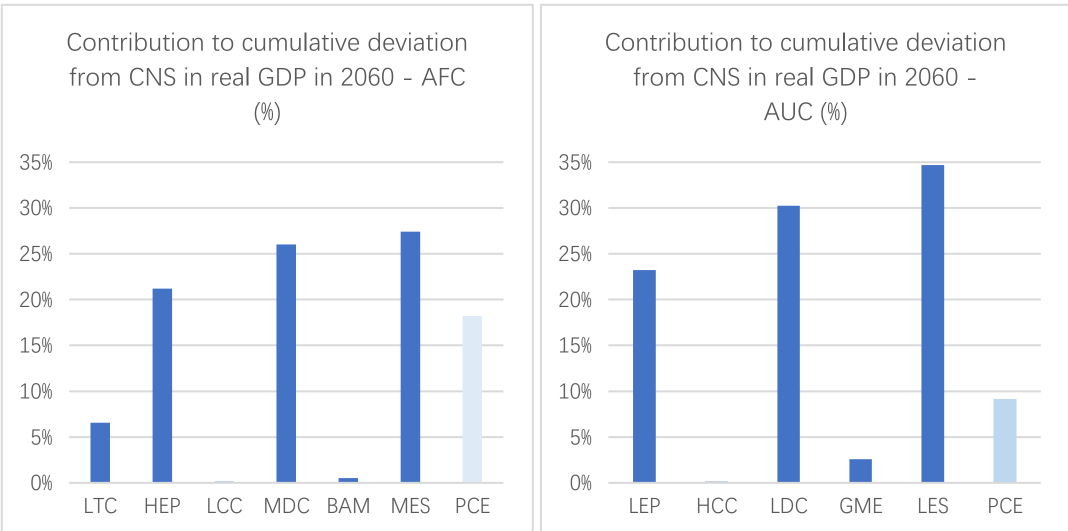
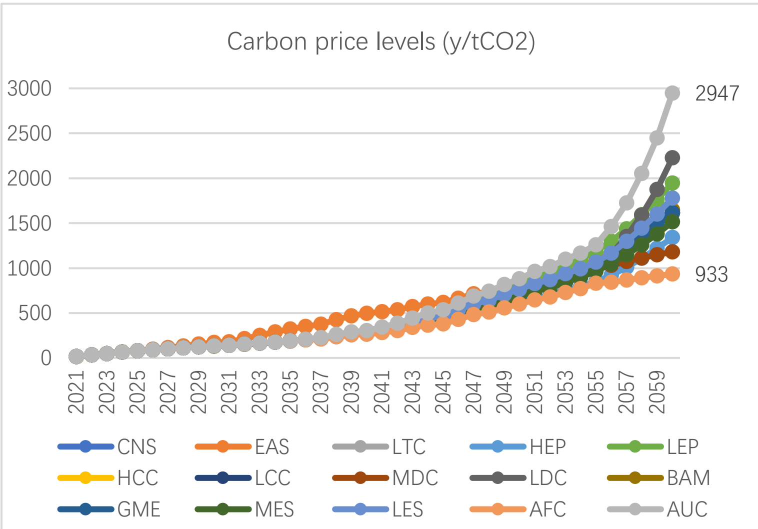


Figure 47: real GDP results decomposition for AFC and AUC, 2060

We show contributions to cumulative deviations in real GDP, in 2060, from CNS, in Figure 47. We observe similar patterns in each group. First, a 0.2 change in the value of power generation CES parameters from the initial values lead to the biggest changes in real GDP. Second, a 20% change in the DACCS contributions from the initial ones lead to the second biggest changes in real GDP. Third, a 20% change in sizes of the energy efficiency and preference shocks lead to the third biggest changes in real GDP. These three types of changes are the most important changes in each group. Fourth, neither a 20% change in the level of unit CCS abatement costs from its initial levels nor changes in BAM/GME assumptions contribute significantly to deviations in real GDP from CNS (less than 5%). Fifth, recycling carbon pricing revenues by cutting labor tax rates contribute to real GDP deviations from CNS only moderately (7%). Sixth, PCEs can lead to significant contributions in both AFC and AUC (18% and 9%, respectively). This last point highlights the importance of combining positive policies.

We show carbon price levels of CNS and the fourteen alternative scenarios in Figure 48. AFC and AUC lead to carbon prices of 933 CNY/tCO2 and 2947 CNY/tCO2 in 2060, respectively. These are significantly different levels of carbon prices. There hence could exist a large range in possible carbon prices that might be required to reach carbon neutrality in 2060. This range does not even cover all possibilities since our tests only allow 20% variations in most assumptions and we do not know the distribution of variations in our assumptions without further analyses. We could tell that, however, LDC and MDC scenarios are the individual alternative scenarios that lead to the highest and lowest carbon price levels, at 2226 and 1180 yuan/tCO2, respectively. LEP and HEP are the individual scenarios that lead to the second highest and second lowest carbon price levels, at 1947 and 1339 CNY/tCO2, respectively. These are followed by LES and MES, at 1777 and 1513 CNY/tCO2, respectively. Other individual scenarios all lead to carbon prices between 1600 and 1700 CNY/tCO2, which are not far from the carbon price level in the CNS.



	in 2060
CNS	1614
EAS	1647
LTC	1614
HEP	1339
LEP	1947
HCC	1615
LCC	1613
MDC	1180
LDC	2226
BAM	1644
GME	1615
MES	1513
LES	1777
AFC	933
AUC	2947

Figure 48: Carbon price levels in CNS and alternative policy scenarios

The cumulative net CO2 emissions between 2020 and 2060 for CNS and the fourteen alternative scenarios are displayed in Figure 49. Under CNS, the net cumulative emissions over the 41 years were 250 btCO2. Five individual scenarios have cumulative emission levels that are noticeably different from the CNS. The most notable difference is in EAS, which emits 238 btCO2 over the same years. This is as predicted since in EAS stronger mitigation efforts were implemented from year 2025, about ten years earlier than they were in the CNS. HEP and MES lead to cumulative emissions that are lower than CNS and LEP and LES lead to cumulative emission that are higher than CNS. The differences are, however, all within a few billion tons. Combining the individual changes, AFC and AUC lead to 247 and 254 btCO2 of cumulative emissions, respectively.

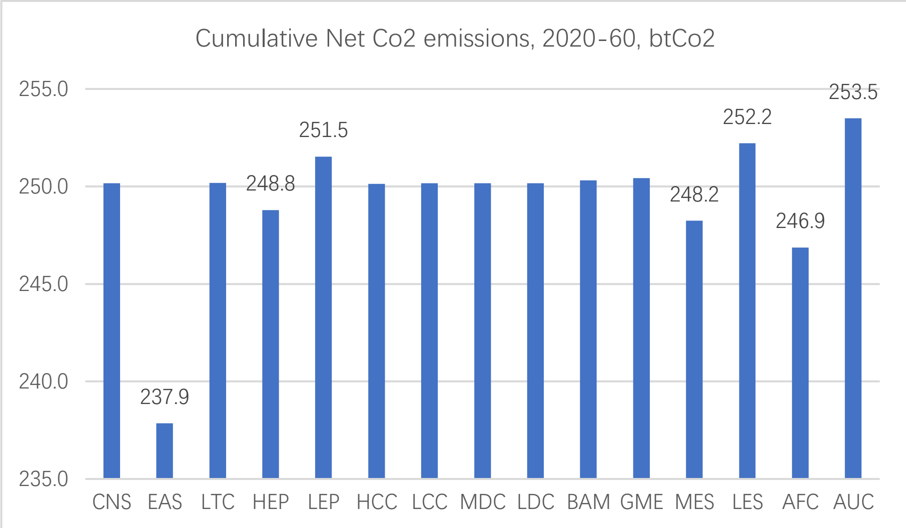


Figure 49: cumulative CO2 emissions in CNS and alternative scenarios

Figure 50 shows the cumulative primary energy consumption for CNS and the fourteen alternative scenarios. Apart from EAS, only two individual alternative scenarios, namely MES and LES, lead to notable different levels of total cumulative primary energy consumption to CNS. MES could afford to have more primary energy consumption because it is easier to switch between fuels with more elastic CES parameters. Nevertheless, the total cumulative primary energy consumption in AFC and AUC are not too far from the CNS level.

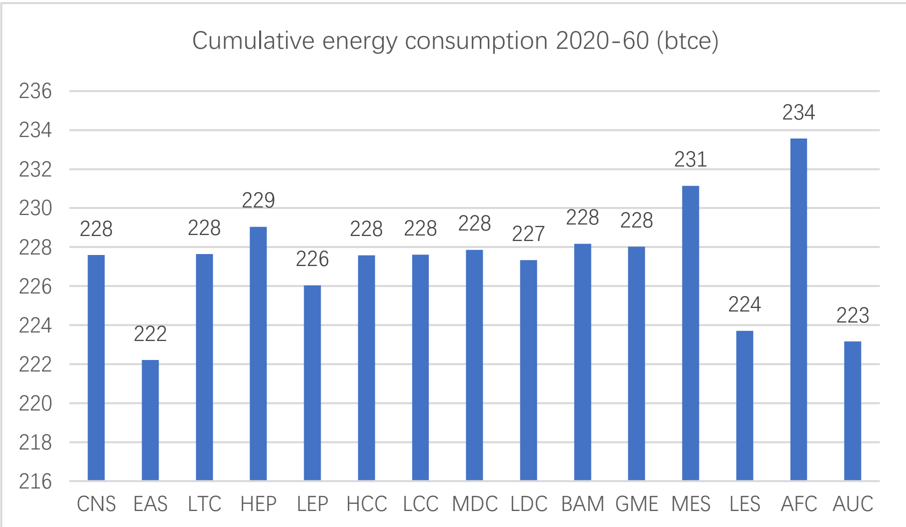


Figure 50: cumulative energy consumptions in CNS and alternative scenarios

We show share of non-fossil fuel in total energy consumption (NFF/E) for CNS and the fourteen alternative scenarios in Figure 51. EAS not only has the lowest cumulative energy consumption, but also the second highest NFF/E among all individual alternative scenarios. These results are consistent with the fact that it has the lowest emissions. We also observe consistent patterns in NFF/E with those in CO2 emissions and primary energy consumption. HEP and MES lead to notably higher NFF/E than CNS whereas LEP and LES lead to notable lower NFF/E. AFC and AUC show that the combination of variations in shocks produce a range of 39.8% - 44.4% for NFF/E, cumulated over 41 years.

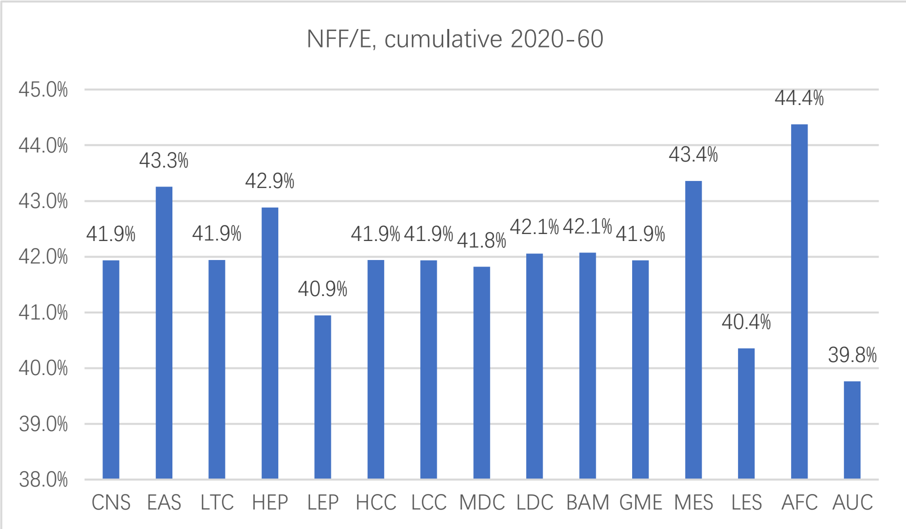


Figure 51: non-fossil fuel share in energy consumption, in CNS and alternative scenarios

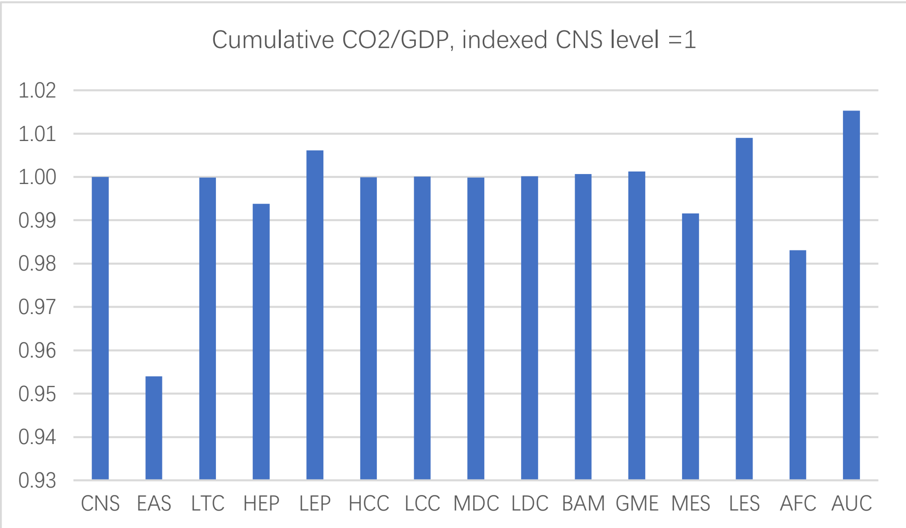


Figure 52: cumulative CO2/GDP, in CNS and alternative scenarios

Figure 52 shows the cumulative emissions intensity of GDP indexes for CNS and the 14 alternative scenarios. We divide cumulative emissions by cumulative GDP between 2020 and 2060 and get cumulative emissions intensity of GDP for the fifteen scenarios. We indexed the CNS level to 1. We find that EAS leads to the lowest cumulative emissions intensity of GDP among all scenarios. All other scenarios lead to similar cumulative emissions intensity of GDP to CNS. These results suggest that, although a carbon neutrality condition is achieved in CNS and all the fourteen alternative scenarios, starting mitigation efforts earlier could result in lower emissions at a given level of GDP over the 41 years span. In another word, earlier actions could make mitigation efforts to be more efficient.

Import of Energy intensity products in BAM and GME

In BAM and GEM, we pay special attention to the results of import demand for energy intensive products. Figure 53 compares cumulative deviations in import demands from CNS, BAM and GME to BCS in 2060. Comparing with CNS, imports of energy intensive goods in both BAM and GEM are significant lower. This is as expected as both alternative policy scenarios restore domestic goods' competitiveness by imposing tax on imports goods.

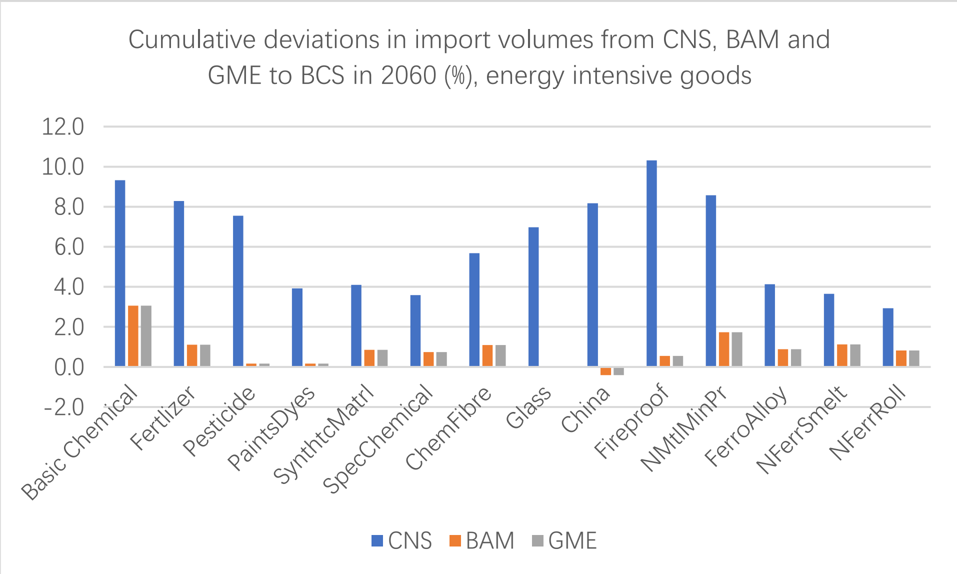


Figure 53: comparison of energy intensive sector import volumes in CNS, BAM and GME, 2060

7. Conclusion and policy implications

We used CHINAGEM-E to analyze the energy and economic implications of reaching carbon neutrality in China. To do so we modified CHINAGEM-E so that it has detailed, updated data and a new power generation nesting structure that suit our analysis. We design a base-case scenario (BCS) to serve as the benchmark to which results are compared. We design a main policy scenario, the carbon neutrality scenario (CNS), to investigate the economic implications for China to reach carbon neutrality. We discuss in detail the assumptions used in these scenarios, including the macroeconomic closure, the energy efficiency and preference shocks and the carbon emissions pathways. We also simulate fourteen alternative scenarios to learn the implications of changes in our underlying assumptions.

The following policy implications can be drawn from our analysis.

1) China can reach its carbon neutrality target in 2060 meanwhile achieving its target to double GDP between 2020 and 2035. Real GDP in our main carbon neutrality scenario is 1.36% lower than it was in the base-case scenario, in 2060. Our results are consistent with the general results in the literature, that strong mitigation effort do not necessarily derail economic development in the long-term, even before taking into the consideration of positive social benefits.

2) The effect of carbon neutrality efforts on employment is very small. The employment in the carbon neutrality scenario is only 0.11% lower than it is in the base case scenario in 2060. Clean

energy sectors employ more persons, and this compensates job losses from fossil fuel-related sectors.

3) China can reach its energy intensity and emissions intensity targets. In fact, our modelling show China has potential to exceed its energy intensity and emissions intensity targets in 2025 and 2030.

4) Emissions are likely to peak before 2030. In fact, our modelling suggests that emissions will reach a ‘flat peak’ at 10.5 billion tonnes of CO2 (btCO2) between 2025 and 2030 even without extra mitigation efforts that are required to lead China to carbon neutrality in 2060. That said, however, carbon neutrality efforts could make the peak to come earlier and at lower levels.

5) Carbon neutrality efforts will reduce energy consumption. Under CNS, total primary energy consumption will likely to ‘flat peak’ in late 2030s, fall gradually, and stabilize at a lower level afterwards. Hence, despite continued economic growth, CNS could help China to decouple GDP growth and energy consumption growth.

6) Non fossil fuel share in total energy consumption need to rise. China aims to increase non-fossil fuel share in total energy consumption to 25% in 2030. In BCS this share is only 23%. In the CNS, however, the share just reaches the target level. It shows that the 25% target is consistent with the carbon neutrality target. By 2060, it will reach 73% in CNS.

7) Electricity consumption will continue to increase. Electricity consumption, which will be composed of more clean energy, will increase to levels above the BCS ones, despite total energy consumption is going to be lower than those in the BCS.

8) CCS technologies are indispensable to carbon neutrality efforts. CCS, including fossil fuel-based CCS, BECCS and DACCS, could help to reduce total emissions between 2020 and 2060 by 20%. Fossil fuel-based CCS could reach a peak of almost 2400 mt CO2 captured and stored in late 2040s.

9) Energy and related sectors are significantly affected by carbon neutrality efforts. Other sectors are affected mildly. Sectors relying on imports receive fewer negative shocks. Sectors sell more to investment are affected more negatively.

10) Earlier actions could make mitigation more efficient. If China begins to implement stronger mitigation efforts than those assumed in the CNS, over the 41 years, China could release a less amount of CO2 emissions per unit of GDP. This, however, would also mean higher carbon prices and more GDP losses. Nevertheless, earlier actions could make the economy to be less emissions intensive over the years between 2020 and 2060.

11) Using carbon pricing revenues to cut pre-existing, distortionary tax rates could lead to smaller reduction in real GDP. We have shown that using carbon pricing revenues to cut labor income tax rates leads to lower GDP costs. The size of the benefits is limited, though. Other revenues-recycling mechanisms shall be investigated in further studies.

12) The size of energy efficiency and preference shocks, the contribution from DACCS, and the value of power generation CES parameters are three important sets of underlying assumptions

that could potentially alter our simulation results. In comparison, cutting labor tax, maintaining energy intensive goods' price competitiveness, and changes in unit abatement costs in CCS have limited energy and economic impacts.

13) Should global mitigation efforts be weaker than China's, it can be in China's interest to adopt BAMs to protect real GDP.

14) Grouping all favorable and all unfavorable changes in our assumptions, real GDP deviations from BCS range between -0.56% and -2.17%, in 2060. There thus might exist large uncertainties in terms of simulation results. More rigorous analyses are required to understand the potential ranges in all of our underlying assumptions.

References:

ADAMS, P. D. & PARMENTER, B. R. 2013. Chapter 9 - Computable General Equilibrium Modeling of Environmental Issues in Australia: Economic Impacts of an Emissions Trading Scheme. *In:* DIXON, P. B. & JORGENSON, D. W. (eds.) *Handbook of Computable General Equilibrium Modeling.* Elsevier.

ALLAN, G., LECCA, P., MCGREGOR, P. & SWALES, K. 2014. The economic and environmental impact of a carbon tax for Scotland: A computable general equilibrium analysis. *Ecological Economics,* 100**,** 40-50.

BABATUNDE, K. A., BEGUM, R. A. & SAID, F. F. 2017. Application of computable general equilibrium (CGE) to climate change mitigation policy: A systematic review. *Renewable and Sustainable Energy Reviews,* 78**,** 61-71.

BATAILLE, C., JACCARD, M., NYBOER, J. & RIVERS, N. 2006. Towards General Equilibrium in a Technology-Rich Model with Empirically Estimated Behavioral Parameters. *The Energy Journal,* 0.

BECKMAN, J., HERTEL, T. & TYNER, W. 2011. Validating energy-oriented CGE models. *Energy Economics,* 33**,** 799-806.

BHATTACHARYYA, S. C. 1996. Applied general equilibrium models for energy studies: a survey. *Energy Economics,* 18**,** 145-164.

BöHRINGER, C. & LöSCHEL, A. 2006. Computable general equilibrium models for sustainability impact assessment: Status quo and prospects. *Ecological Economics,* 60**,** 49-64.

BOVENBERG, L. & DE MOOIJ, R. 1994. Environmental Levies and Distortionary Taxation. *American Economic Review,* 84**,** 1085-89.

CHINA NATIONAL PETROLEUM CORPORATION ECONOMIC AND TECHNOLOGY RESEARCH INSTITUTE 2020. World Energy Outlook 2050.

CUI, Q., LIU, Y., ALI, T., GAO, J. & CHEN, H. 2020. Economic and climate impacts of reducing China's renewable electricity curtailment: A comparison between CGE models with alternative nesting structures of electricity. *Energy Economics,* 91**,** 104892.

DIXON, P. B. & RIMMER, M. T. 2002. *Dynamic general equilibrium modelling for forecasting and policy - a practical guide and documentation of MONASH,* Bingley, UK, Emerald.

ENERGY FOUNDATION CHINA 2020. Synthesis Report 2020 on China's Carbon Neutrality: China's New Growth Pathway: from the 14th Five Year Plan to Carbon Neutrality.

FAN, J.-L., XU, M., LI, F., YANG, L. & ZHANG, X. 2018. Carbon capture and storage (CCS) retrofit potential of coal-fired power plants in China: The technology lock-in and cost optimization perspective. *Applied Energy,* 229**,** 326-334.

FENG, S., HOWES, S., LIU, Y., ZHANG, K. & YANG, J. 2018. Towards a national ETS in China: Cap-setting and model mechanisms. *Energy Economics,* 73**,** 43-52.

FENG, S. & ZHANG, K. 2018. Fuel-factor nesting structures in CGE models of China. *Energy Economics,* 75, 274-284.

FUJIMORI, S., MASUI, T. & MATSUOKA, Y. 2014. Development of a global computable general equilibrium model coupled with detailed energy end-use technology. *Applied Energy,* 128, 296-306.

GOLDMAN SACHS 2020. China Net Zero: The clean tech revolution.

GOULDER, L. 1995. Environmental taxation and the double dividend: A reader's guide. *International Tax and Public Finance,* 2, 157-183.

GUO, J.-X. & HUANG, C. 2020. Feasible roadmap for CCS retrofit of coal-based power plants to reduce Chinese carbon emissions by 2050. *Applied Energy,* 259, 114112.

HANCOCK, L. & RALPH, N. 2021. A framework for assessing fossil fuel 'retrofit' hydrogen exports: Security-justice implications of Australia's coal-generated hydrogen exports to Japan. *Energy,* 223, 119938.

HERMELING, C., LöSCHEL, A. & MENNEL, T. 2013. A new robustness analysis for climate policy evaluations: A CGE application for the EU 2020 targets. *Energy Policy,* 55, 27-35.

HUANG, X., CHANG, S., ZHENG, D. & ZHANG, X. 2020. The role of BECCS in deep decarbonization of China's economy: A computable general equilibrium analysis. *Energy Economics,* 92, 104968.

JEWELL, J. 2011. The IEA Model of Short-Term Energy Security (MOSES).

JIA, Z. & LIN, B. 2021. How to achieve the first step of the carbon-neutrality 2060 target in China: The coal substitution perspective. *Energy,* 233, 121179.

JIANG, J., RUI, Z., HAZLETT, R. & LU, J. 2019. An integrated technical-economic model for evaluating CO2 enhanced oil recovery development. *Applied Energy,* 247, 190-211.

KURZ, W. A., DYMOND, C. C., WHITE, T. M., STINSON, G., SHAW, C. H., RAMPLEY, G. J., SMYTH, C., SIMPSON, B. N., NEILSON, E. T., TROFYMOW, J. A., METSARANTA, J. & APPS, M. J. 2009. CBM-CFS3: A model of carbon-dynamics in forestry and land-use change implementing IPCC standards. *Ecological Modelling,* 220, 480-504.

LIU, Y. 2020. Carbon emissions peaking and energy transision. *Conference on China Energy Transition and Econoimc Development under Carbon Neutrality.* Wuhan.

LIU, Y. & LU, Y. 2015. The Economic impact of different carbon tax revenue recycling schemes in China: A model-based scenario analysis. *Applied Energy,* 141, 96-105.

MAI, Y., DIXON, P. B. & RIMMER, M. T. 2010. CHINAGEM: A Monash-Styled Dynamic CGE Model of China. Centre of Policy Studies, Victoria University.

NORDHAUS, W. D. 1992. An Optimal Transition Path for Controlling Greenhouse Gases. *Science,* 258, 1315-1319.

NORDHAUS, W. D. & YANG, Z. 1996. A Regional Dynamic General-Equilibrium Model of Alternative Climate-Change Strategies. *The American Economic Review,* 86**,** 741-765.

OTTO, V. M., LöSCHEL, A. & DELLINK, R. 2007. Energy biased technical change: A CGE analysis. *Resource and Energy Economics,* 29**,** 137-158.

PALTSEV, S., MORRIS, J., KHESHGI, H. & HERZOG, H. 2021. Hard-to-Abate Sectors: The role of industrial carbon capture and storage (CCS) in emission mitigation. *Applied Energy,* 300**,** 117322.

PROJECT SYNTHESIS REPORT WRITING GROUP 2020. China long-term low carbon development strategy and transition pathway analysis - a synthesis report. *China population, resources and environment,* 30**,** 1-25.

QUARTON, C. J. & SAMSATLI, S. 2020. The value of hydrogen and carbon capture, storage and utilisation in decarbonising energy: Insights from integrated value chain optimisation. *Applied Energy,* 257**,** 113936.

TAPIA, J. F. D., LEE, J.-Y., OOI, R. E. H., FOO, D. C. Y. & TAN, R. R. 2016. Optimal CO2 allocation and scheduling in enhanced oil recovery (EOR) operations. *Applied Energy,* 184**,** 337-345.

VENNEMO, H., HE, J. & LI, S. 2014. Macroeconomic Impacts of Carbon Capture and Storage in China. *Environmental and Resource Economics,* 59**,** 455-477.

WANG, J., LU, H. & PENG, H. 2008. System Dynamics Model of Urban Transportation System and Its Application. *Journal of Transportation Systems Engineering and Information Technology,* 8**,** 83-89.

WENG, Y., CAI, W. & WANG, C. 2021. Evaluating the use of BECCS and afforestation under China's carbon-neutral target for 2060. *Applied Energy*.

YIN, S., ZHANG, S., ANDREWS-SPEED, P. & LI, W. 2017. Economic and environmental effects of peak regulation using coal-fired power for the priority dispatch of wind power in China. *Journal of Cleaner Production,* 162**,** 361-370.

ZHA, D. & ZHOU, D. 2014. The elasticity of substitution and the way of nesting CES production function with emphasis on energy input. *Applied Energy,* 130**,** 793-798.

ZHANG, X.-L. 2020. Low-carbon energy transition scenario analysis under the 2060 carbon neutrality target. *China Power Electric Enginerring Society Annual Meeting* Beijing.

ZHU, Y., ZHAI, R., QI, J., YANG, Y., REYES-BELMONTE, M. A., ROMERO, M. & YAN, Q. 2017. Annual performance of solar tower aided coal-fired power generation system. *Energy,* 119**,** 662-674.

Zuo, X. Peng, X. Yang, X. Adams, P. D. and Wang, M. (2020), Population Ageing and the Impact of Later Retirement on the Pension System in China: An Applied Dynamic General Equilibrium Analysis, CoPS Working paper, G-303, April 2020 Melbourne, Australia.

Appendix 1: List of industries in the CHINAGEM-E model

1	Crops	Farming
2	Forestry	Forestry
3	Livestock	Animal Husbandry
4	Fishing	Fishery
5	AgriSrvces	Service in Support of Agriculture
6	CoalMineProc	Mining and Washing of Coal
7	CrudeOil	Extraction of Petroleum
8	Gas_Cnv	Extraction of Conventional Natural Gas
9	Gas_NCnv	Extraction of Non-conventional Natural Gas
10	FerrOre	Mining of Ferrous Metal Ores
11	NFerrOre	Mining of Non-Ferrous Metal Ores
12	NMtlMine	Mining of Non-metal Ores
13	MiningSrvces	Service in Support of Mining & Other Ores
14	GrainMillOil	Grinding of Grains
15	AnimalFood	Processing of Forage
16	VegetOils	Refining of Vegetable Oil
17	SugarRef	Manufacture of Sugar and Sugar Products
18	MeatProds	Slaughtering and Processing of Meat
19	FishProc	Processing of Aquatic Product
20	VegFrtNuts	Vegetables, Fruits, Nuts & Other Agricultural Products
21	ConvenFoods	Manufactures of Convenience Food
22	DairyProds	Manufacture of Dairy Products
23	FlavFermPrds	Manufacture of Flavouring and Ferment Products
24	OtherFood	Manufacture of Other Foods
25	AlcoholBev	Manufacture of Alcohol and Wine
26	OtherBev	Manufacture of Soft Drinks
27	PurifiedTea	Manufacture of Purified Tea
28	Tobacco	Manufacture of Tobacco
29	CottonSpin	Spinning and Weaving, Printing and Dyeing of Cotton and Chemical Fibre
30	WoolSpin	Spinning and Weaving, Dyeing and Finishing of Wool
31	HempSpin	Spinning and Weaving of Hemp and Tiffany
32	KnitMill	Manufacture of Knitted Fabric and Its Products
33	TextProc	Manufacture of Textile Products
34	Apparel	Manufacture of Textile Wearing Apparel
35	Leather	Manufacture of Leather, Fur, Feather and its Products
36	Footwear	Footwear
37	WoodProds	Processing of Timbers, Manufactures of Wood, Bamboo, Rattan, Palm and Straw Products
38	Furniture	Manufacture of Furniture
39	PaperProd	Manufacture of Paper and Paper Products
40	PrintingRecd	Printing, Reproduction of Recording Products
41	ArtsCrafts	Arts and Crafts
42	CultSportGds	Manufactures of Articles for Culture, Education, Sports and Entertainments
43	PetrolRef	Processing of Petroleum, Nuclear Fuel
44	Coking	Processed Coal

45	BasicChem	Manufacture of Basic Chemical Raw Materials
46	Fertlizr	Manufacture of Fertilizers
47	Pesticide	Manufacture of Pesticides
48	PaintsDyes	Manufacture of Paints, Printing Inks, Pigments and Similar Products
49	SynthtcMatrl	Manufacture of Synthetic Materials
50	SpecChemical	Manufacture of Special Chemical Products
51	ChemDly	Manufacture of Chemical Products for Daily Use
52	Medicine	Manufacture of Medicines
53	ChemFibre	Manufacture of Chemical Fibre
54	RubberPrd	Manufacture of Rubber
55	PlasticPrd	Manufacture of Plastic
56	CementLime	Manufacture of Cement, Lime and Plaster
57	CmtLimePrds	Manufacture of Products of Cement, Lime and Plaster
58	BrickStone	Manufacture of Bricks, Stone and Other Building Materials
59	Glass	Manufacture of Glass and Its Products
60	China	Manufacture of Pottery
61	Fireproof	Manufacture of Fire-resistant Materials
62	NMtlMinPr	Manufacture of Graphite and Other Non-metallic Mineral Products
63	IronSmelt	Steel-making
64	SteelSmelt	Rolling of Steel
65	FerroAlloy	Iron-smelting and Smelting of Ferroalloy
66	NFerrSmelt	Non-ferrous Metals and their Alloys
67	NFerrRoll	Rolling of Non-Ferrous Metals
68	ProcMetals	Manufacture of Metal Products
69	Boilers	Manufacture of Boiler and Prime Mover
70	MtlwrkMch	Manufacture of Metalworking Machinery
71	Lifters	Manufacture of Lifters
72	PumpValvMach	Manufacture of Pump, Valve and Similar Machinery
73	CultOffcMach	Manufacture of Cultural & Office Machinery
74	OthMachinery	Manufacture of Other General Purpose Machinery
75	MinMetConMch	Manufacture of Special Purpose Machinery for Mining, Metallurgy and Construction
76	ChmTimNmtMch	Manufacture of Special Purpose Machinery for Chemical Industry, Processing of Timber and Non-metals
77	AgrForFshMch	Manufacture of Special Purpose Machinery for Agriculture, Forestry, Animal Husbandry and Fishery
78	OthSpcEqp	Manufacture of Other Special Purpose Machinery
79	MotorVhc	Manufacture of Automobiles
80	MVParts	Manufacture of Automobile Components
81	RailEqp	Manufacture of Railroad Transport and Urban Metro Equipment
82	Ships	Manufacture of Boats and Ships
83	OthTransEqp	Manufacture of Other Transport Equipment
84	Generators	Manufacture of Generators
85	PwrTrnEqp	Manufacture of Equipment for Power Transmission and Distribution and Control
86	WireCablOptc	Manufacture of Wire, Cable, Optical Cable and Electrical Appliances
87	Batteries	Manufacture of Battery
88	HhldElec	Manufacture of Household Electric and Non-electric Appliances
89	OthElecEqp	Manufacture of Other Electrical Machinery and Equipment
90	Computers	Manufacture of Computers

91	CommunctnEqp	Manufacture of Communication Equipment
92	BrdCstEqpRdr	Manufacture of Broadcasting Equipment and Radar
93	AudiovislEqp	Manufacture of Audio Visual Apparatus
94	ElctronParts	Manufacture of Electronic Component
95	OthElctrnEqp	Manufacture of Other Electronic Equipment
96	OthMeasEqp	Manufacture of Measuring Equipment
97	OthManufact	Other Manufacture Products
98	ScrapRecyc	Scrap, Waste, Recycled Products
99	RepairMachEq	Manufacture of Metal Products, Repairs of Machinery and Equipment
100	HydroElec	Production of Hydropower
101	CoalElec	Production of Coal-fired Electricity
102	GasElec	Production of Gas-fired Electricity
103	NuclearElec	Production of Nuclear Power
104	Wind_OnSh	Production of Wind Power On-shore
105	Wind_OffSh	Production of Wind Power Off-shore
106	SolarElec	Production of Solar Power
107	BioElec	Production of Bioelectricity
108	ElecDist	Electricity Transmission and Distribution
109	GasSupply	Production and Distribution of Gas
110	WaterSupply	Production and Distribution of Water
111	ResConstruct	Construction of Household Buildings
112	CivilEngCons	Civil Engineering
113	InstaltnCons	Construction Installation
114	DecorCons	Building Decoration, Renovation and Other Construction Services
115	WholesaleTrd	Wholesale Trades
116	RetailTrade	Retail Trades
117	RailPass	Railway Passenger Transportation
118	RailFreight	Rail Freight Transportation and Transport Support Activities
119	UrbanTrans	Urban Public Transport and Highway Passenger Transport
120	RoadTrans	Road Cargo Transportation and Transport Support Activities
121	WaterPasTrpt	Water Passenger Transport
122	WaterCagTrpt	Water Cargo Transportation and Transport Support Activities
123	AirPass	Air Passenger Transportation
124	AirFreight	Air Cargo Transportation and Transport Support Activities
125	PipeTrns	Pipeline Transportation
126	TransService	Multimodal Transport and Transportation Agents Services
127	Warehousing	Loading, Unloading and Transportation Agent Services and Storage
128	Post	Post
129	Hotels	Hotel
130	Restaurant	Catering Services
131	Telecomms	Telecommunications
132	RTSTrService	Radio, Television and Satellite Transmission Services
133	InternetServ	Internet and Related Services
134	SftwarServic	Software Services
135	ITService	Information Technology Services
136	MonetServ	Monetary Finance and other Financial Services
137	Finance	Capital Market Services

138	Insurance	Insurance
139	RealEstate	Real Estate
140	Leasing	Leasing
141	BusinessSrv	Business Services
142	Research	Research and Experimental Development
143	TechSrvc	Professional Technical Services
144	SciTechSvc	Science and Technology Promotion and Application Services
145	WaterTechSvc	Water Management
146	EcoEnvManage	Ecological Protection and Environmental Governance
147	PubFacltyMan	Public Facilities and Land Management
148	ResidentSrvc	Residence Services
149	OthService	Other Services
150	Education	Education
151	Health	Health
152	SocialWork	Social Work
153	JournlPublsh	Journalism and Publishing Activities
154	ArtsFilmTV	Broadcasting, Movies, Televisions and Audio Visual Activities
155	CulturalArt	Cultural and Art Activities
156	Sports	Sports Activities
157	Entertainmnt	Entertainment
158	SocWelfare	Social Security
159	PublicAdmin	Public Management and Social Organization

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1 Crops	Farming
2 Forestry	Forestry
3 Livestock	Animal Husbandry
4 Fishing	Fishery
5 AgriSrvces	Service in Support of Agriculture
6 CoalMineProc	Mining and Washing of Coal
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8 Gas	Extraction of Natural Gas
9 FerrOre	Mining of Ferrous Metal Ores
10 NFerrOre	Mining of Non-Ferrous Metal Ores
11 NMtlMine	Mining of Non-metal Ores
12 MiningSrvces	Service in Support of Mining & Other Ores
13 GrainMillOil	Grinding of Grains
14 AnimalFood	Processing of Forage
15 VegetOils	Refining of Vegetable Oil
16 SugarRef	Manufacture of Sugar and Sugar Products
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19 VegFrtNuts	Vegetables, Fruits, Nuts & Other Agricultural Products
20 ConvenFoods	Manufactures of Convenience Food
21 DairyProds	Manufacture of Diary Products
22 FlavFermPrds	Manufacture of Flavouring and Ferment Products
23 OtherFood	Manufacture of Other Foods
24 AlcoholBev	Manufacture of Alcohol and Wine
25 OtherBev	Manufacture of Soft Drinks
26 PurifiedTea	Manufacture of Purified Tea
27 Tobacco	Manufacture of Tobacco
28 CottonSpin	Spinning and Weaving, Printing and Dyeing of Cotton and Chemical Fibre
29 WoolSpin	Spinning and Weaving, Dyeing and Finishing of Wool
30 HempSpin	Spinning and Weaving of Hemp and Tiffany
31 KnitMill	Manufacture of Knitted Fabric and Its Products
32 TextProc	Manufacture of Textile Products
33 Apparel	Manufacture of Textile Wearing Apparel
34 Leather	Manufacture of Leather, Fur, Feather and its Products
35 Footwear	Footwear
36 WoodProds	Processing of Timbers, Manufactures of Wood, Bamboo, Rattan, Palm and Straw Products
37 Furniture	Manufacture of Furniture
38 PaperProd	Manufacture of Paper and Paper Products
39 PrintingRecd	Printing, Reproduction of Recording Products
40 ArtsCrafts	Arts and Crafts
41 CultSportGds	Manufactures of Articles for Culture, Education, Sports and Entertainments
42 PetrolRef	Processing of Petroleum, Nuclear Fuel
43 Coking	Processed Coal
44 BasicChem	Manufacture of Basic Chemical Raw Materials
45 Fertlizr	Manufacture of Fertilizers
46 Pesticide	Manufacture of Pesticides

47 PaintsDyes	Manufacture of Paints, Printing Inks, Pigments and Similar Products
48 SynthtcMatrl	Manufacture of Synthetic Materials
49 SpecChemical	Manufacture of Special Chemical Products
50 ChemDly	Manufacture of Chemical Products for Daily Use
51 Medicine	Manufacture of Medicines
52 ChemFibre	Manufacture of Chemical Fibre
53 RubberPrd	Manufacture of Rubber
54 PlasticPrd	Manufacture of Plastic
55 CementLime	Manufacture of Cement, Lime and Plaster
56 CmtLimePrds	Manufacture of Products of Cement, Lime and Plaster
57 BrickStone	Manufacture of Bricks, Stone and Other Building Materials
58 Glass	Manufacture of Glass and its Products
59 China	Manufacture of Pottery
60 Fireproof	Manufacture of Fire-resistant Materials
61 NMtlMinPr	Manufacture of Graphite and Other Non-metallic Mineral Products
62 IronSmelt	Steel Making
63 SteelSmelt	Rolling of Steel
64 FerroAlloy	Iron-smelting and Smelting of Ferroalloy
65 NFerrSmelt	Non-ferrous metals and their alloys
66 NFerrRoll	Rolling of Non-Ferrous Metals
67 ProcMetals	Manufacture of Metal Products
68 Boilers	Manufacture of Boiler and Prime Mover
69 MtlwrkMch	Manufacture of Metalworking Machinery
70 Lifters	Manufacture of Lifters
71 PumpValvMach	Manufacture of Pump, Valve and Similar Machinery
72 CultOffcMach	Manufacture of Cultural & Office Machinery
73 OthMachinery	Manufacture of Other General Purpose Machinery
74 MinMetConMch	Manufacture of Special Purpose Machinery for Mining, Metallurgy and Construction
75 ChmTimNmtMch	Manufacture of Special Purpose Machinery for Chemical Industry, Processing of Timber and Non-metals
76 AgrForFshMch	Manufacture of Special Purpose Machinery for Agriculture, Forestry, Animal Husbandry and Fishery
77 OthSpcEqp	Manufacture of Other Special Purpose Machinery
78 MotorVhc	Manufacture of Automobiles
79 MVParts	Manufacture of Automobile Components
80 RailEqp	Manufacture of Railroad Transport and Urban Metro Equipment
81 Ships	Manufacture of Boats and Ships
82 OthTransEqp	Manufacture of Other Transport Equipment
83 Generators	Manufacture of Generators
84 PwrTrnEqp	Manufacture of Equipment for Power Transmission and Distribution and Control
85 WireCablOptc	Manufacture of Wire, Cable, Optical Cable and Electrical Appliances
86 Batteries	Manufacture of Battery
87 HhldElec	Manufacture of Household Electric and Non-electric Appliances
88 OthElecEqp	Manufacture of Other Electrical Machinery and Equipment
89 Computers	Manufacture of Computers
90 CommunctnEqp	Manufacture of Communication Equipment
91 BrdCstEqpRdr	Manufacture of Broadcasting Equipment and Radar
92 AudiovislEqp	Manufacture of Audio Visual Apparatus

93 ElctronParts	Manufacture of Electronic Component
94 OthElctrnEqp	Manufacture of Other Electronic Equipment
95 OthMeasEqp	Manufacture of Measuring Equipment
96 OthManufact	Other Manufacture Products
97 ScrapRecyc	Scrap, Waste, Recycled Products
98 RepairMachEq	Manufacture of Metal Products, Repairs of Machinery and Equipment
99 HydroElec	Production of Hydropower
100 CoalElec	Production of Coal-fired Electricity
101 GasElec	Production of Gas-fired Electricity
102 NuclearElec	Production of Nuclear Power
103 WindElec	Production of Wind Power
104 SolarElec	Production of Solar Power
105 BioElec	Production of Bioelectricity
106 ElecDist	Electricity Transmission and Distribution
107 GasSupply	Production and Distribution of Gas
108 WaterSupply	Production and Distribution of Water
109 ResConstruct	Construction of Household Buildings
110 CivilEngCons	Civil Engineering
111 InstaltnCons	Construction Installation
112 DecorCons	Building Decoration, Renovation and Other Construction Services
113 WholesaleTrd	Wholesale Trades
114 RetailTrade	Retail Trades
115 RailPass	Railway Passenger Transportation
116 RailFreight	Rail Freight Transportation and Transport Support Activities
117 UrbanTrans	Urban Public Transport and Highway Passenger Transport
118 RoadTrans	Road Cargo Transportation and Transport Support Activities
119 WaterPasTrpt	Water Passenger Transport
120 WaterCagTrpt	Water Cargo Transportation and Transport Support Activities
121 AirPass	Air Passenger Transportation
122 AirFreight	Air Cargo Transportation and Transport Support Activities
123 PipeTrns	Pipeline Transportation
124 TransService	Multimodal Transport and Transportation Agents Services
125 Warehousing	Loading, Unloading and Transportation Agent Services and Storage
126 Post	Post
127 Hotels	Hotel
128 Restaurant	Catering Services
129 Telecomms	Telecommunications
130 RTSTrService	Radio, Television and Satellite Transmission Services
131 InternetServ	Internet and Related Services
132 SftwarServic	Software Services
133 ITService	Information Technology Services
134 MonetServ	Monetary Finance and other Financial Services
135 Finance	Capital Market Services
136 Insurance	Insurance
137 RealEstate	Real Estate
138 Leasing	Leasing
139 BusinessSrv	Business Services
140 Research	Research and Experimental Development
141 TechSrvc	Professional Technical Services

142 SciTechSvc	Science and Technology Promotion and Application Services
143 WaterTechSvc	Water Management
144 EcoEnvManage	Ecological Protection and Environmental Governance
145 PubFacltyMan	Public Facilities and Land Management
146 ResidentSrvc	Residence Services
147 OthService	Other Services
148 Education	Education
149 Health	Health
150 SocialWork	Social Work
151 JournlPublsh	Journalism and Publishing Activities
152 ArtsFilmTV	Broadcasting, Movies, Televisions and Audio Visual Activities
153 CulturalArt	Cultural and Art Activities
154 Sports	Sports Activities
155 Entertainmnt	Entertainment
156 SocWelfare	Social Security
157 PublicAdmin	Public Management and Social Organization